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Technical Report

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COMBAT VEHICLE TECHNOLOGY REPORT

MAY 1992

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By

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This report is an overview of technologies related to combat vehicles. A discussion of each technical area includes the objectives to be achieved as well as major accomplishments. The technical areas are propulsion, mobility, survivability, vehicle electronics (Vetronics), robotics, simulation, integration, manufacturing, and materials/composites.

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1.0 INTRODUCTION

1.1. Major Tank Developments

The United States Army had a tank force smaller than that of Poland at the outset of World War II in 1939. By the time the U.S. entered the war in 1941, its heavy industry had begun to gear up for war production and by 1945 had produced about 287,000 armored vehicles, more than any other nation. American tanks and armored vehicles formed the backbone of nearly every allied armored force except that of the Soviet Union.

For nearly 20 years after WW II, the U.S. was the principal source of armored vehicles for NATO. By the 1960s, this situation began to change when France and Germany began to manufacture main battle tanks. France and Britain were very successful in exporting their vehicles to Third World countries, which had previously relied exclusively on the U.S. These countries began to challenge American technological leadership in NATO, though U.S. designs, especially in the area of self-propelled howitzers and armored personnel carriers, remained in big demand.

The troubled state of American tank development in the 1960s was another factor in the trend away from American technical dominance in armored vehicles. The U.S. embarked on a series of very highly sophisticated armored vehicles such as the Main Battle Tank MBT-70, M551 Mauler and Vigilante, most of which died an early death because of insoluble technical problems, high complexity, unrealistic costs, and funding shortages. As a result, in the 1970s, the U.S. remained equipped with armored vehicles over 10 years old in design and technological advance. The only means of enhancement was by modification.

The Warsaw Pact had long enjoyed a numerical edge over NATO but this was blunted by the technical advantages enjoyed by the armored vehicles of NATO. As a result, there was a major surge in Soviet armored vehicle development, including fielding of a new family of armored vehicles. The Warsaw Pact armored vehicles included the T-62 combat tank, BMP infantry combat vehicle, ZSU-23-4 SHILKA air defense gun vehicle, and SA-6 air defense missile vehicle, which challenged NATO's technological lead.

The U.S. response to the Soviet challenge was a multifaceted effort to maintain the conventional balance of forces in Europe. The U.S. Army had never attempted to match the Soviet Army tank for tank but had relied for many years on a strategy of tactical air power, high-quality antitank missiles and a smaller, but better trained and equipped tank force. A new armored vehicle program initiated in the early 1970s has produced new designs including the M1 Abrams Main Battle Tank, M2/M3 Bradley Fighting Vehicles, the Multiple Launched Rocket System (MLRS), and surface to surface missiles to replace or augment conventional tube artillery. These weapon systems were developed with less emphasis on the complicated technical ingenuity used in the 1960s, and more emphasis was placed on proven technological advances. There have been many important technical breakthroughs in armor design, radar and laser fire control systems, advanced ammunition and night vision which have enabled the U.S. Army to realize the goals first set in the 1960s.

1.2. Technologies Related to Combat Vehicles

Excellent contributions from various TACOM organizations in several technical areas are gratefully acknowledged. In addition, a literature survey was made for innovative developments presented in reports and articles of various authoritative references (see List of References).

A Matrix summarizing technological innovations is shown as table 1-1.

TABLE 1-1

TECHNOLOGIES RELATED TO COMBAT VEHICLES

Technical Area	Technology	Objective	Remarks
Propulsion	o Low Heat Rejection (Adiabatic) Engine o Ceramic Materials	Improved Reliability, Efficiency, Reduced Maintenance, Small System Size	The technology required for a low-heat-rejection engine is achieved by making use of high-temperature materials and new design principles to insulate combustion system components. Benefits of this technology include the reduction of the cooling system, smoother combustion, improved multifuel characteristics, improved fuel economy, and a reduction in propulsion system volume and weight.
	o Advanced Integrated Propulsion System (AIPS)	Volume/Weight Reduction, Greater Efficiency, Maintainability, RAM-D	The performance requirements for the diesel or turbine engine propulsion system must at least equal that of the M1 Abrams Tank but must be housed in an envelope approximately half that of the M1. Volume reduction is very important because of its impact on vehicle weight and the creation of additional space for weapon stations. A 40-50 percent improvement in fuel economy is expected.
	o Turbine Engine	Increased power, Reduced Fuel Consumption	A program is nearing completion to demonstrate thermal barrier coatings (TBC) for air-cooled turbine blades and nozzles for operation at 2700 degree F rotor inlet temperature. TBCs have been used to improve cooling effectiveness and permit higher engine cycle operating temperatures, while minimizing cooling air requirements resulting in increased specific power due to a higher maximum cycle temperature.

TABLE 1-1 (CONTINUED)
TECHNOLOGIES RELATED TO COMBAT VEHICLES

Technical Area	Technology	Objective	Remarks
Propulsion	o Variable Geometry High-Pressure Ratio, Broad Range, High-Efficiency Turbochargers	Improved Efficiency, Reduced Smoke Signature	Through this technology, engine airflow can be tailored to the fuel delivered at each engine speed and load. As a result of the electronics used to control the variable geometry features, ambient temperature and pressure changes can be automatically compensated. Also, slight degradations in engine performance due to wear and pressure drops within the induction system can also be partially compensated. Efficient responsive air charging systems would provide adequate air charging under all operating conditions. Combat vehicle acceleration, including acceleration from a standing start, will be improved.
	o Self-Cleaning Air Filter	Fewer Engine Failures, Reduced Maintenance Requirements, Increased Operational Capability	Several concepts have completed proof of principle. Durability testing is being done prior to Abrams production decision.
	o Automatic Transmission	Improved Transmission Efficiency Through Elimination of Driver's Gear Selection Variability	Automatic transmissions provide superior shift performance as well as faster, smoother operation.
	o Electric Drive	Improved Flexibility in Tracked Vehicles Design	Improvements in both rotating components and power conditioning will make electric drive a viable, competitive technology. To date, work is limited to studies and component development, leading to vehicle demonstration.

TABLE 1-1 (CONTINUED)
TECHNOLOGIES RELATED TO COMBAT VEHICLES

Technical Area	Technology	Objective	Remarks
Mobility	o Double-Pin, Replaceable Pad Track	Reduce Track O&S (Operation and Support) Costs by Improving Service Life	Double-pin, replaceable pad track designs are being developed within the framework of weight classes of vehicles commonality for both current and future armored combat vehicles.
	o Improved Track Rubber	Improve Track Service Life	With greater vehicle mobility performance demands and system weight, the dynamic load experienced by the track increase at an exponential rate.
	o External Suspension (Hydropneumatic Suspension System)	Replace Torsion Bars and Reduce Volume Below Hull Floor, Equalize Loads	Efforts have been under way for several years to develop an external suspension system for tracked vehicles. The system would consist of independent hydropneumatic suspension units for each wheel station.
	o Adaptive Suspension	Vehicle Springing and Damping System Which Senses and Automatically Adapts to Terrain	Development of microprocessor controlled logic, integrated with externally mounted suspension system design, will sense hull motion, determine terrain conditions, and automatically adjust springing and damping characteristics.
	o Track Tension Adjuster	Maintain Uniform Track Tension for All Mobility Conditions	Two approaches are being pursued to develop a dynamic track tension adjuster: a) modify current systems based on British design, b) competitively solicit industry.

TABLE 1-1 (CONTINUED)
TECHNOLOGIES RELATED TO COMBAT VEHICLES

Technical Area	Technology	Objective	Remarks
Survivability	o Improved Armor	Enhanced Battlefield Survivability Against Kinetic Energy and Shaped Charges	This will provide protection against kinetic energy and shaped charge threats with a minimum weight penalty. Armor materials and systems can be used as appliques to provide principal or added armor protection to current and future vehicles. Improvements in armor performance have been achieved in a variety of ways. Conventional materials (rolled armor, aluminum, etc.) have been improved. New materials such as composite and ceramics have been developed to provide armor protection. Combinations of materials and geometrical arrangements have been developed. These new lightweight armor systems will be able to provide the same ballistic protection as a monolithic steel armor design at weight savings of 50% or more.
	o Advanced Cast Armor	Intricate Armor Configurations and Improved Producibility	The use of lost-foam casting processes enable the manufacture of intricate armor shapes and configurations with the goal of providing maximum protection with minimum weight. In addition, the producibility of the armor configurations is improved.
	o Signature Reduction	Enhanced Battlefield Survivability Through Minimized Acoustic, Infrared, Laser, Photometric and Radar Signatures	Validated computer models are being used in the design and evaluation of signature modification and suppression devices. Advanced countermeasures are being integrated in test beds to reduce vehicle signatures and their detection and identification by threat acquisition systems.
	o Hit Avoidance Countermeasures	Enhanced Battlefield Survivability Through the Use of Advanced Integrated Sensor and Countermeasure Reaction Systems	By the use of advanced laser warning, millimeter wave warning, NBC warning, and other threat sensing, the modern combat vehicle will be able to avoid detection, and if detected, avoid being hit through the automation of an integrated threat warning and countermeasure reaction system.

TABLE 1-1 (CONTINUED)
TECHNOLOGIES RELATED TO COMBAT VEHICLES

Technical Area	Technology	Objective	Remarks
Survivability	o Protected Vision (Directed Energy Hardening)	Enhanced Crew Function Through Protection of Vision Devices From Laser Threat Enhanced Battlefield Survivability Through Hardening of Tank Unity Vision Systems Against Directed Energy Threats	The application of filters and other optical protection devices to vision blocks and periscopes ensure protection of the vehicle crew from laser or any other directed optical threat. Combat vehicle crews require protection against the threat of blinding or sensor damage by lasers. Current technology allows protection against fielded laser hazards (ruby, Nd: YAG) with ongoing development to address future multiline and broadband threats.
Electronics	o Vetronics	Optimized Crew and Vehicle Effectiveness, Improved Reliability, Availability, and Maintainability, Real Time Integration with the Electronic Battlefield	Combat vehicles of the future are expected to have on board a "smart" system using microprocessors that enable the vehicle to monitor its own subsystems and communicate with the electronic battlefield outside. Miniaturized electronic components will be used to develop a vehicle integration architecture that will more efficiently integrate a vehicle's electrical and electronic subsystems. Rather than adding these subsystems one at a time, it would be more efficient to optimize electronics in a systemized manner.
	o Multiplex Circuitry	Improved Information Handling	Multiplex circuits are required to handle increasing amounts of information at very high speeds. A microcomputer is used to control and manage a multiplex wiring system.
	o Optronics	Improved Electronic Circuits/Communication	Optical energy could be used in place of electrical energy. This would eliminate the need for conversion to and from electrical energy.
	o Fiber Optics	Reduction of Electronic Wiring Harnesses	The requirement for more space in vehicles for additional equipment is being addressed by the development of fiber optic systems. Fiber optic buses will be used in place of wire.

TABLE 1-1 (CONTINUED)
TECHNOLOGIES RELATED TO COMBAT VEHICLES

Technical Area	Technology	Objective	Remarks
Electronics	o Flat Panel Technology	Crew Displays in Vehicles Which Require Little Volume and Provide Common Display for Crew	The increasing amounts of information made available to the vehicle crew requires a quick response, vivid, graphic information display system which utilizes little space.
	o Laser Threat Detection Technology	Increased Survivability	Laser Warning Receivers (LWR) can detect enemy lasers and direct countermeasures.
	o Laser Navigational System Technology	Improved Navigation	This would improve the method of determining the location of a combat/robotic vehicle by using a jam-free navigational system. Present navigational methods (using radio signals from a network of earth satellites to provide positioning information) can be jammed by enemy countermeasures.
	o Integration of Propulsion System Controls	Provide Improvements in Performance, Efficiency, Signature, and Fault Analysis	Achievable with today's hardware, this is primarily a software problem.
	o Electronic Transmission Clutch Control System with Microcomputer	Improved Reliability, Durability, and Shift Performance of Hydraulically Controlled Transmissions	The electronic transmission clutch control replaces unreliable mechanical linkages, requires no adjustment, and can accommodate sophisticated control algorithms for combining combat vehicle steering and propulsion.
	o Technology Application	Harness Combat Data That Can Be Used at the Maneuver Level	The benefit of combining various electronic technologies will result in a vehicle integrated intelligent battlefield management system.

TABLE 1-1 (CONTINUED)
TECHNOLOGIES RELATED TO COMBAT VEHICLES

Technical Area	Technology	Objective	Remarks
Robotics	o Autonomous Mobility Control	Unmanned Navigation of Vehicles in an Unconstrained Natural Environment.	Will permit force multiplication, since fewer soldiers will be required to conduct combat operations. Limited autonomy will reduce the communication load between remote-controlled vehicles and their crews.
	o Robot Communications	Medium Band with Radio Link which is Secure, Survivable, and Does Not Require Line-of-Sight Transmission.	As robots become more autonomous, communication with their supervisors will be reduced, but still needed. A medium data rate link is needed for near- and mid-term robotic applications.
	o Control & Status Data Rate Reduction	Minimize the Quantity of Data Transmitted Between Controllers and Robotic Vehicles.	Communications bandwidth available on the battlefield will not allow use of wide-band communication among robots and controllers. High-bandwidth/high-frequency communication requires line-of-sight transmissions.
	o Crew Aids	Application of Robotics to Reduce Crew Workload and Increase Effectiveness.	Crew aids will include automatic route and battle planners, as well as expert systems for combat decision making.
	o Automated Mission Packages	Automated Mission-related Functions for Applications with Robotic Mobility Systems.	Automation of mission applications include antiarmor, reconnaissance, as well as mine clearing missions.
	o Robotic Platform Design	Exploiting the Inherent Possibilities in Robot Chassis Design Due to the Removal of the Soldier from the Vehicle.	Opportunities for reduced size, lightly armored designs which can, if desired, be made to look like manned systems.

TABLE 1-1 (CONTINUED)
TECHNOLOGIES RELATED TO COMBAT VEHICLES

Technical Area	Technology	Objective	Remarks
Simulation	o Vehicle Dynamics Simulation	Improved, More Accurate Design and Testing of Vehicles; Reduction of Prototype Testing	A dynamic simulation computer is used in the design, performance, and evaluation of various vehicle components and systems. This is an efficient and effective method of optimizing system design.
	o Test Track Simulation in Laboratory	Improve Quality of Testing and Reduce Costs	Laboratory simulation accelerates testing time, reduces start-up costs, ensures test repeatability, and reduces uncontrolled variables in the testing process.
	o Finite Element Analysis (Modeling/ Simulation)	Predict Structural Strength of Vehicle System Components	A component is simulated as a collection of material fragments called elements which can elastically deform (flex) or conduct heat.
	o Vehicle Production Simulation	Improved Manufacturing Process Flow Through Simulation of Manufacturing and Assembly Operations	Through the use of computer simulation, the manufacturing and assembly operations of new or existing vehicle systems can provide the optimum shop layout. The goal is to reduce bottlenecks and optimize process flow, lowering overall production costs.

TABLE 1-1 (CONTINUED)
TECHNOLOGIES RELATED TO COMBAT VEHICLES

Technical Area	Technology	Objective	Remarks
Integration	o Packaging of Many Potential Technologies	Optimization of Vehicle Configuration, Volume, Weight, and Silhouette, Reduction in Vehicle Complexity	Threat and mission requirements of future vehicles are creating space, weight, and complexity problems. Through the application of integration techniques, the packaging of the technologies becomes more efficient resulting in a more effective combat vehicle.
Manufacturing	o Electrostatic Welding Using Controlled Cooling of Welded Metal	Elimination of Hydrogen Cracking and Improved Toughness in Weld Joint	Current welding processes produce poor welds on heavy armor sections because of hydrogen cracking and enlarged grain structure.
	o Composite Materials	Reduced Costs and Increased Productivity	Many vehicle components are fabricated from more than one part and can be replaced with a single molded component.
	o Laser Heat Treating	Improvement in Precise Depth Control, Savings in Reduced Machining, Increase in Service Life of Part	The location and depth of a high-wear area in a part can be treated and controlled very precisely.
	o Laser Welding	Reduced Manufacturing Costs, Faster Welding, Higher Quality Welds	Automated laser welding systems are being used in certain manufacturing applications.
	o Laser Cutting o Laser Drilling	Improved Manufacturing Productivity	Lasers are specified in manufacturing processes because they do not have any of the drawbacks normally associated with contact processes, such as tool wear while cutting or drilling. Lack of physical contact with the workpiece and precise control over the total heat input results in little or no mechanical distortion and minimal thermal distortion.
	o Producibility	Reduced Production Costs By Designing Parts for Production	Producibility is the lowering of production costs by designing new vehicle components for ease of production or analyzing current designs and production techniques with the goal of optimizing production.

TABLE 1-1 (CONTINUED)
TECHNOLOGIES RELATED TO COMBAT VEHICLES

Technical Area	Technology	Objective	Remarks
Materials/ Composites	o Plastic Resins and Inorganic Materials (Composite Structure)	Improved Strength to Weight Ratio and Improved Protection Against Ballistic Threats	Various material combinations provide significant advantages over conventional materials used for tank turret, hull, and lightweight howitzers.
	o Armor Materials	Improved Ballistic Resistance	Composite/hybrid materials which may be metallic, ceramic, or organic can be used to replace metals in many applications with weight and cost reductions and improved ballistic capability.
	o Metal Matrix Composites	Improved Performance from Lighter, Stronger Metals	Composites add the following enhancements to many vehicular components: increased strength, wear resistance, fatigue life, thermal insulation, decreased thermal expansion, and reduced manufacturing costs.
	o Advanced Ceramics	Better Engine Performance and Fuel Economy	The versatility of ceramics and their unique combination of properties make them key subjects for further development. They are lightweight, wear resistant, excellent insulators, and extremely strong at high temperatures.
	o Corrosion Prevention and Control	Improved Overall Vehicle Function and Life Through Reduced Corrosion	Corrosion prevention and control reduces vehicle downtime and failure due to corrosion of components. Through the use of composites, specialized plating and coatings, operational readiness will be enhanced in all types of environments.

2.Ø PROPULSION

The Army must be capable of movement without restrictions of terrain, obstacles, weather, or visibility. The areas of emphasis for achieving these goals include lightening the force and reducing manpower burden both in vehicle operation and maintenance. Tactical mobility is essential and will require lightweight, compact, and common platforms. To mitigate limitations to mobility, due to weather, meteorological sensor data and computer estimates of mobility, must be utilized.

A combat vehicle's propulsion system consists of the engine and transmission, their associated cooling systems, air filtration, internal fuel storage, plumbing, ducting, and accessories, such as the alternator. In tracked vehicles, the transmission system includes steering and braking functions, besides power transmission.

Technical opportunities exist in almost every propulsion subsystem. Packaging of diesel engines has progressed to the extent that propulsion system size and weight will be reduced. The propulsion system occupies about one-third to one-half of the internal hull volume. Since approximately one and a half tons of armor is required for every cubic meter of hull volume encompassed, propulsion system volume has a very direct effect on vehicle weight, as well as on vehicle size. Although much can be done to minimize propulsion system volume via accepting modest power-to-weight ratios, reducing fuel storage under armor, and using manual instead of automatic transmissions, these decisions involve definite operational trade-offs. Advanced propulsion systems will significantly reduce propulsion system volume for any given vehicle weight, power-to-weight ratio, and set of operational constraints. Technology can be used to enhance the performance of components as follows:

The differences in design between commercial and military engines are due to differences in trade-offs between the design objectives. Combat vehicle engines tend to optimize high power-to-volume, responsiveness, high power-to-weight, and multifuel capability at the expense of high reliability, low-fuel consumption, reduced maintenance and operating costs, and low initial costs.

Improvements in engine technology now in development will slowly improve the engine performance and extend service life. There will be significantly higher pressure ratios, improved performance through the compressors, increased use of ceramic coatings for thermal barriers in the engine, ceramic bearings needing no lubrication, improvements in cooling (where required) to extend service life, electronic fuel controls, and improved component efficiency. The overall effect significantly increases engine efficiency resulting in smaller, lighter weight engines with improved fuel consumption. Reliability and maintainability will be improved over current conventional combat vehicle propulsion systems. Requirements in the areas of startability, fuel tolerance, and fuel economy in particular may be met in the future with the present advance in technology. Modularity is stressed for improved sustainability.

Advances in transmission technology are not dramatic, reflecting a more evolutionary process. Improvements in ratio coverage and reductions in parasitic losses will provide efficiency improvements. Hydrodynamic brakes may provide similar advantages. The integration of the engine and transmission design, as well as new approaches such as an electric hybrid system, may provide more substantial reductions in the transmission envelope.

2.1 Adiabatic Engine/Ceramic Materials

Application of the first law of thermodynamics states that all energy put into an engine through fuel combustion must ultimately appear as either work on the crankshaft (which can be translated into movement of the vehicle), heat rejected to the coolant, lubricant, or directly to the environment, or as energy exiting the exhaust system. To increase work on the crankshaft, the "low heat rejection" engine decreases the energy lost as heat rejected to the coolant, thus boosting the thermodynamic efficiency. It is also possible to extract energy from the hot exhaust gases by use of a turbocharger, a centrifugal blower driven by exhaust gas turbines and used to supply the exhaust gases to the intake of the engine at a higher pressure than the surrounding atmosphere.

Advanced adiabatic technology will support advances in the areas of engine friction minimization through concepts such as ringless pistons and ceramic unlubricated bearings. The higher operating temperature imposes more stringent demands on the lubricant. Solid or dry film cylinder wall lubrication and/or air lubrication will permit operation at temperatures exceeding 450 degrees Centrigrade. Advanced component development is also to be carried out in the valve, fuel injection, cylinder head, and cylinder block areas.

Far-term technologies for application to the adiabatic diesel engine include variable valve timing. Though not a major impact on engine size, this will reduce air flow (and, therefore, the need for filtering) considerably. Development of engine concepts, materials, and fuel processes will provide improved automotive performance.

Benefits of the adiabatic engine include virtual elimination of the conventional cooling system, smoother combustion (less noise and smoke), improved multifuel characteristics, a minimum of 30% improvement in fuel economy over current highly efficient diesel engines, and a 40% reduction in engine system volume and weight. Elimination of cooling systems removes a major source of engine failures, while simplifying maintenance. This concept provides more power and improved efficiency, because thermal energy is converted to useful power through the use of turbomachinery and high-temperature materials, rather than being lost to the cooling and exhaust systems. A shorter ignition delay may allow use of a lower compression ratio, with a consequent decrease in motoring power that could contribute to a higher mechanical efficiency and better fuel economy, in turn.

The application of ceramic materials has made possible the adiabatic diesel concept that reduces under-armor cooling system size requirements by about one-half and improves fuel economy significantly. Ceramic applications on turbine engines promise enhancement of cycle efficiency, thus reducing engine size, fuel and airflow requirements with attendant reductions in induction and exhaust space claims.

Requirements for improved engines will be met by development of an advanced high-output adiabatic diesel engine, making use of high-temperature materials such as monolithic ceramics or ceramic fiber reinforced metals or ceramic coatings. These materials would be used to insulate combustion system components including pistons, piston rings, cylinder block, cylinder liner, cylinder head, intake and exhaust valves, exhaust manifold or liners, and the turbocharger turbine. On a gas turbine engine, these materials could also be used to insulate rotors or stators, combustors, and regenerators. These components would be made from these ceramic materials or more conventional materials with ceramic coatings applied. Engine components with ceramic coatings (acting as heat barriers) will increase cycle temperatures, with a resultant efficiency increase. This will allow the use of metallic components at higher operating temperatures, with accompanying improved performance.

The major requirements of ceramic materials for a low heat rejection engine are low thermal conductivity, low specific heat, high strength, high fracture toughness, high thermal shock resistance, good wear resistance, thermal expansion matching that of iron or steel, and chemical inertness for high resistance to erosion and corrosion. Progress in ceramic materials technology is still needed in the areas of durability, large-scale manufacture, production quality, inspection techniques, and cost.

Toughened partially stabilized zirconia (PSZ) ceramics possess a unique combination of material properties making them suitable for adiabatic engine components. These properties include high strength and fracture toughness, high thermal shock resistance, low thermal conductivity and coefficient of friction, excellent wear and corrosion/erosion resistance, and an expansion coefficient similar to steel. Compared to other materials, partially stabilized zirconia ceramics satisfy all requirements for adiabatic engine systems best. Magnesium partially stabilized zirconia (Mg-PSZ) has the highest fracture toughness of all the PSZ ceramics and can be heat-treated in several ways to modify its microstructure for specific applications.

This will allow combustion at higher than conventional operating temperatures near an adiabatic operating condition, without the use of a conventional cooling system. The term "adiabatic", which means "without heat loss", is a misnomer, since the interchange of heat between gases inside an insulated cylinder and the cylinder walls is not eliminated, although it is reduced significantly. A more appropriate term is "low heat rejection" engine. The engine will use a power recovery turbine to capture the greatly increased exhaust gas energy and will be highly fuel efficient, compact, lightweight, and low cost per horsepower.

A new alloy called Syalon has some remarkable properties and contains elements such as silicon, aluminum, oxygen, and nitrogen. This mixture is stronger than steel, diamond-hard, and as light as aluminum. It also has exceptional resistance to wear and thermal shock, is a good electrical insulator, and retains its compressive and tensile strength at temperatures up to 1400 degrees Centigrade.

Current applications under development include ceramic engine combustion chamber components, bearings, seals, turbocharger rotors, and adiabatic engine parts. The basic processing Syalon powder can be cold formed by pressing, injection molding, casting or extrusion. "Preform" parts are easily machined prior to final sintering.

The hardness of Syalon ceramic makes it highly advantageous for wear and friction applications as in engines. Its very low thermal expansion gives unusual dimensional stability, which is an important requirement for ceramic components.

Ceramic thermistors (resistors) with a large positive temperature coefficient of electrical resistance are finding many vehicle applications as self-regulating heaters. These highly reliable materials provide heat at a preselected temperature, require no external controls, and can operate in direct contact with petroleum-based fuels. The ceramic materials are crystalline in nature and undergo a phase change in crystalline structure and electrical resistance increase at a predetermined temperature.

Positive Temperature Coefficient (PTC) ceramic is most often formed from barium titanate. Other elements such as strontium or lead may be substituted for the barium in the titanate compound to vary the temperature/resistance properties of the ceramic material. PTC heaters have many advantages including: (1) minimum power requirements, (2) no control circuitry (self-regulating), (3) temperature independent of voltage supply variations and ambient temperature, (4) fast response, (5) high reliability, (6) preselected operating temperature and (7) not affected by petroleum fuels.

PTC ceramic applications include choke controls, diesel fuel heater elements, manifold heaters and fuel evaporators for cold engine operating conditions.

2.2 Advanced Integrated Propulsion System (AIPS)

AIPS is an advanced integrated propulsion system, suitable for a heavy combat vehicle. The system includes diesel or turbine engine, transmission, fuel for one battlefield day, air filtration, cooling system, inlet and exhaust ducting, diagnostics and maintainability concepts, and signature reduction. The goals for this propulsion system are to deliver approximately 10 percent more power in half the volume, with fuel economy improvement of 50 percent over the current M1A1 power pack. Volume reduction is very important because of the significant impact on vehicle weight (influenced by the armor requirement over the propulsion system) and the creation of additional space available for weapon stations, etc. The expected fuel economy improvement of 50 percent better than the M1A1 power pack will result in a 50 percent reduction in operation and support costs associated with the M1A1. Fuel tolerance will also be improved. Targets demanding substantial improvements in reliability, maintainability, and durability have been set. Significant use of electronic diagnosis and prognosis is required to achieve these targets. Low heat rejection technology is used for the diesel engine concept.

In 1984, development contracts for two competing concepts were awarded to General Electric (gas turbine) and Cummins Engine Company (diesel). This program culminates in a laboratory demonstration and a vehicle demonstration on the Component Advanced Technology Test Bed (CATTB). The retention of two contractors enhances competition and will allow the Army to decide between a diesel and gas turbine-based system on the basis of hardware demonstration. The first engines and transmissions are under test.

2.3 Turbine Engine Technology

The Turbine Engine Technology Program, through an ongoing series of investigations and demonstrations, supports component technology for an advanced turbine engine for combat vehicles. Two major component investigation programs were initiated in late FY85 to provide support for future advanced engines having 1500 degrees Centigrade maximum cycle temperatures.

A 43-month contract was awarded to Williams International in August 1985 to develop and test thermal barrier coatings (TBC) for air-cooled turbine blades and turbine nozzles for operation at 1500 degrees Centigrade rotor inlet temperature. TBCs have been used to improve cooling effectiveness in gas turbine engine components. Increased cooling effectiveness will permit a higher engine cycle operating temperature while minimizing cooling air requirements resulting in increased specific power due to a higher maximum cycle temperature. In addition, TBC will reduce specific fuel consumption due to a reduction in cycle losses associated with cooling air requirements. An assessment of the coating technology was made by surveying the published literature and consulting with coating specialists. Appropriate coatings were selected for testing and evaluation. Test rigs with proper instrumentation are ready for testing the selected coatings.

Starting in August 1985, AiResearch Manufacturing Company began working on the development of advanced high-temperature recuperator technology under a fifty-month contract. The technology objectives include extended durability, design flexibility for broader application potential, low strategic material content, low cost, and high-temperature (1000 degrees Centigrade) capability. Nitrogen dispersion strengthened stainless steel (NDS 300), which met the latter three objectives, was the material selected for this technology development. Conceptual design of the recuperator was completed. Processing of the material and property evaluation were the principal activities during the first half of the program. AiResearch has designed and built a furnace to process the NDS 300 alloy. Tests were conducted to evaluate the properties of the processed material. Braze joints were formed and tested for strength and corrosion resistance. Fins were successfully formed. Module development currently is in progress. The fifty-month effort will include fabrication and testing of module and full-scale recuperators to demonstrate durability and design flexibility. The technology developed under the program is expected to complement the gas turbines to be developed for use in future Army vehicles.

2.4 Variable Geometry Turbocharger

Improved turbomachinery such as variable geometry turbochargers and variable geometry turbomachinery for gas turbine engines and their control systems, can increase air-handling ability and thus horsepower, reduce idle and part load fuel consumption, and improve responsiveness. By use of a variable geometry turbocharger, engine airflow can be tailored to the fuel delivered at each engine speed and load until an engine or turbocharger mechanical limit is reached, such as maximum cylinder firing pressure. Another advantage of a variable geometry turbocharger is a large increase in engine backup torque, along with a rated power increase, if the previous baseline turbocharger match was not designed for rated power. Significant improvements in brake specific fuel consumption are gained, due to an optimum control of the air-to-fuel ratio and improved compressor and turbine efficiencies. Transient response is greatly improved in the areas of reduced smoke and increased instantaneous horsepower (due to more air and fuel being available for combustion). Improved throttle response results in a reduction in typical turbocharger lag, due to maintaining higher turbocharger speed at low-load conditions. As a result of the electronics used to control the variable geometry features, the turbocharger can automatically partially compensate for ambient temperature and pressure changes. In addition, slight degradations in engine performance due to wear, and pressure drops within the vehicle induction system can also be partially compensated by the turbine controls.

This technology is most readily identifiable with military vehicles where durability, simplicity, and fuel economy are sacrificed in order to achieve high power outputs from relatively small power plant volumes. Current turbochargers are slow to respond to changes in load. Consequently, vehicle acceleration is sluggish, particularly from a standing start. Efficient responsive air-charging systems can provide adequate air charging under all operating conditions and would alleviate the current transient response deficiency at an acceptable level of smoke signature. Combat vehicle acceleration, including acceleration from a standing start, would be able to meet current critical response requirements.

Specific power output from a diesel engine is primarily a direct function of the amount of fuel and air available for combustion. In a naturally aspirated engine, the specific power output is limited by the minimum air/fuel ratio acceptable in terms of exhaust smoke. In a turbocharged diesel engine, maximum specific power output can be limited by either a minimum air/fuel ratio or, if excess air is delivered, by exceeding maximum cylinder firing pressures. A common practice used for limiting the performance in a turbocharged diesel is to match the turbocharger efficiencies at rated speed and load. Another more commonly used method is to match the turbocharger for high output at medium speeds and loads and then primarily bypass some of the exhaust gases around the turbocharger turbine to avoid overpressuring the engine at higher engine speeds and loads. Both methods result in a significant amount of energy wasted, causing reduced power output (as compared to an optimum match for that speed and load) and an increase in engine brake specific fuel consumption.

2.5 Self-Cleaning Air Filter

Removal of dust from a combat vehicle's intake air is an absolute must, if the engine is to operate satisfactorily for more than a few hours in a dusty environment. Air filters, which can be cleaned during normal vehicle operation and without crew access to the air induction system, offer major improvements in maintainability, reliability and availability.

Self-cleaning air filters will reduce engine failures due to dust ingestion and increase the operational capability of the vehicles. The filter material in the air cleaner is continuously cleaned by a vacuuming process. The self-cleaning air filter uses a backflushing cleaning system. In this system, an air jet cleaning nozzle backflushes the filter media, and a vacuum receiver collects the dislodged dust. An automatic mechanism cycles the nozzle and receiver over the filter element until the airflow restriction is reduced to a predetermined level. By minimizing air restriction through its self-cleaning feature, such an air cleaner, will result in higher average available engine power. Incorporating a dust detector and indicator into the air filter design will provide the ability to alert the operator of an air filter malfunction.

2.6 Development of Automatic Transmission

The development of automatic transmissions for tracked combat vehicles has provided many benefits. Automatic transmissions allow a propulsion system to be designed to meet specific user requirements and provide assurance that the vehicle will be operated as designed, mainly by eliminating the variability of driver gear selection. Automatic transmissions provide superior shift performance, since shifts are not only faster but are consistently smoother. Automated synchronization and clutch modulation protect the driveline from driver error and extend transmission life. Driver fatigue is reduced and maneuverability improved, potentially decreasing trip times. In the area of transmissions, non-Newtonian oils for hydrostatics or hydromechanics offer improved efficiencies.

Similarly, regenerative mechanical steering units, either separate or incorporated into the automatic transmissions, also enhance the combat vehicle's performance. Transmission improvements will decrease power losses, thus increasing net power output, as well as reducing cooling and volume requirements.

2.7 Electric Drive System

The common tracked armored vehicle uses a mechanical-hydrokinetic or mechanical-hydrostatic transmission consisting of an automatic or semiautomatic gearbox, torque converters, hydraulic pumps and motor, shafts, universal joints and final drives. While efficient and capable of excellent performance, design flexibility is limited by mechanical connections.

By contrast, the electric drive system electronically transmits power to the drive sprockets, resulting in overall design flexibility advantages. There is a reduction in maintenance. Continuously variable ratio control is inherent.

The present electric drive system development has been impaired by the lack of suitable motors, controls, and power semiconductors. Recent technological advances have made electric drive systems more competitive. The idea of electric drive goes back to 1917 when the French built a 23-ton tank using this concept. The Germans, British, Belgians and Russians have also built similar type tanks. The U.S. built several experimental tanks with electric propulsion systems, such as the T23, T23E3, T25 and T26.

3.0 MOBILITY

The success of ground combat vehicle mission accomplishment is directly dependent upon the vehicle system's ability to aggressively negotiate all types of terrain and accurately shoot on the move. The track and suspension components of a conventional torsion bar system (Figure 3-1) work together as a dynamically interrelated system, which provides the mobility interface between the vehicle hull and the ground. The mobility system design, which is based on specific vehicle performance requirements and established all-terrain operational capability, also provides vibration isolation. The characteristics of the track and suspension mobility system determine vehicle ride quality and directly influence gun platform stability.

Military ground combat vehicle mobility requirements far surpass those of commercial tracked vehicle applications with respect to speed and all-terrain operational capability (Figure 3-2). The basic tracked vehicle mobility problem is also complicated by performance and survivability issues unique to the combat theater of operations. The technology base work is essential because there are neither commercial requirements for heavy, high-speed, all-terrain vehicles, nor an industry technology base readily adaptable to meet Army ground combat vehicle requirements. Revolutionary advances in design and materials technology are needed to meet the demand for increased mobility with greater durability and reliability, while reducing maintenance burden, weight and cost.

Technical opportunities exist for both track and suspension component development. Structural and elastomeric material advances will be applied to reduce track weight, without compromising structural integrity, and to increase field service life for significant annual track operating and support (O&S) cost reduction. The development of externally mounted suspension systems will eliminate all conventional torsion bar suspension volume under armor space claim, and will have a very direct effect on reducing vehicle weight and silhouette. Key technology base advancement efforts address the development of computer-aided design and analysis capabilities and field correlated laboratory simulation testing methodologies. Integration of these capabilities will eliminate the iterative cut/test/fix development approach and reduce future mobility systems development time and cost by up to 50 percent.

The track is essentially a prepared roadway which the combat vehicle lays down, travels over, and picks up again. This movable roadway carried by high-speed military tracked vehicles is the basis for their superior cross country mobility performance. It functions as a surface which transfers the propulsion system drive output from the sprocket to a multiwheel drive over the entire ground area supporting the vehicle to obtain tractive effort. The surface design maximizes ground contact area for traction and distributes ground pressure over as large an area as possible to minimize sinkage and provide limited water propulsion. Generally, a combat vehicle track

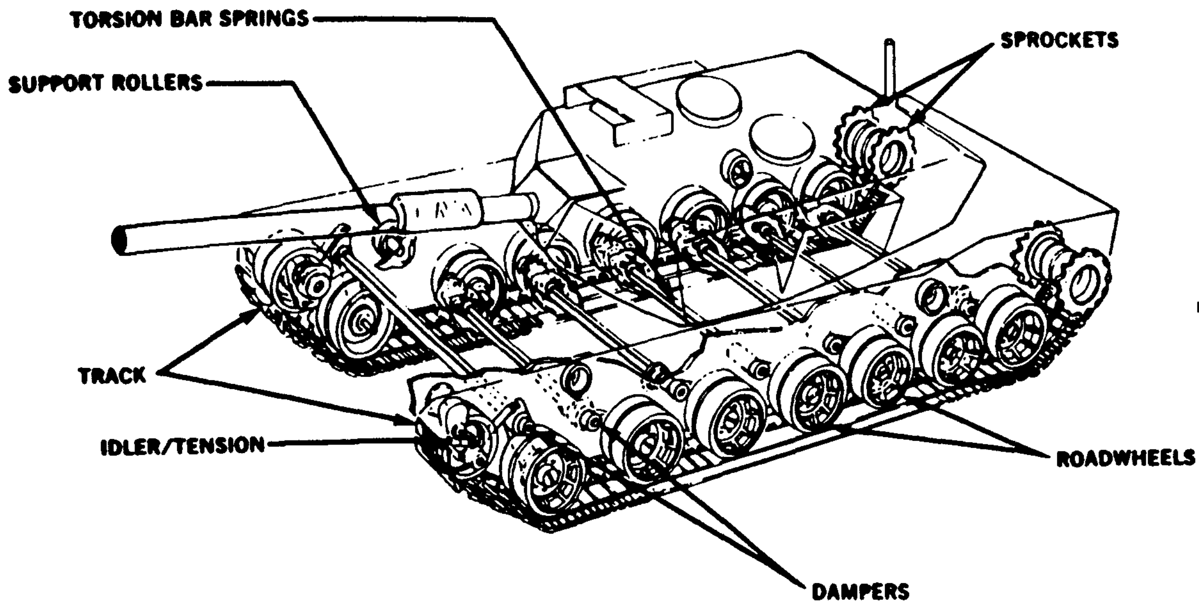

Figure 3-1. Conventional Torsion Bar System Components

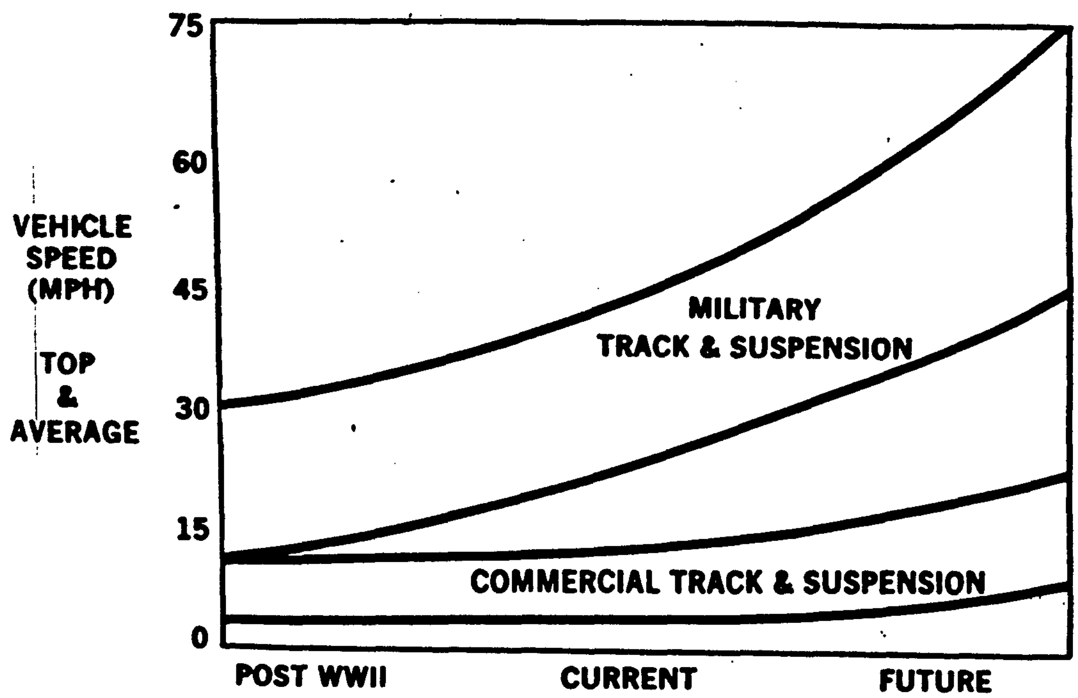

Figure 3-2. Tracked Vehicle Mobility Trends

is comprised of flexibly interconnected blocks which provide the equivalent of a ramp over holes and obstacles. It provides a smooth path for the roadwheels to run over, as well as guide faces which keep the wheels on the track.

Historically, combat vehicle track design philosophy has been predicated upon development of an individual track for each vehicle, consonant with the specific vehicle peculiar mission performance requirements. Over the years, many different types of track designs have been generated in response to these requirements (Figure 3-3).

Current combat vehicle track designs utilize a block and pin arrangement, with a resilient rubber bushing around the pin to provide a flexible joint. Block and pin type tracks employ either single or double pin construction at the hinge joint, coupled with single or double block body configuration. The single-pin design is generally limited to 25-30 tons maximum vehicle weight application. Double-pin configurations are not vehicle weight restricted, and provide greater service life by virtue of their increased bushing load-bearing area (essentially twice that of an equivalent width single-pin track design). The roadwheel path surface is rubber, integral to the track body, to maximize roadwheel tire life and provide maximum vibration isolation. The centerguide can be either integral to the track body, or a separate additional connecting member, and serves to keep the track under the roadwheels. The rubber ground pad can be either integral to the track body or replaceable.

Improvements in both materials and design technology now under development will be applied to gradually increase track service life and reduce weight. Technical goals address the need for development of combat effective design concepts with extended durability and reliability, while concurrently providing reduced weight, maintenance burden, and peacetime O&S costs for the next generation of armored combat vehicles. Commonality within specific vehicle weight classes is being stressed for interoperability and improved sustainability objectives.

The fundamental objective of tracked vehicle suspension design is to place between the track and hull a strong, simple, rugged, and easily maintained system of sufficient flexibility to minimize shock and vibration transmitted to the hull, support the sprung mass in a stable manner, and distribute the weight of the vehicle uniformly along the track.

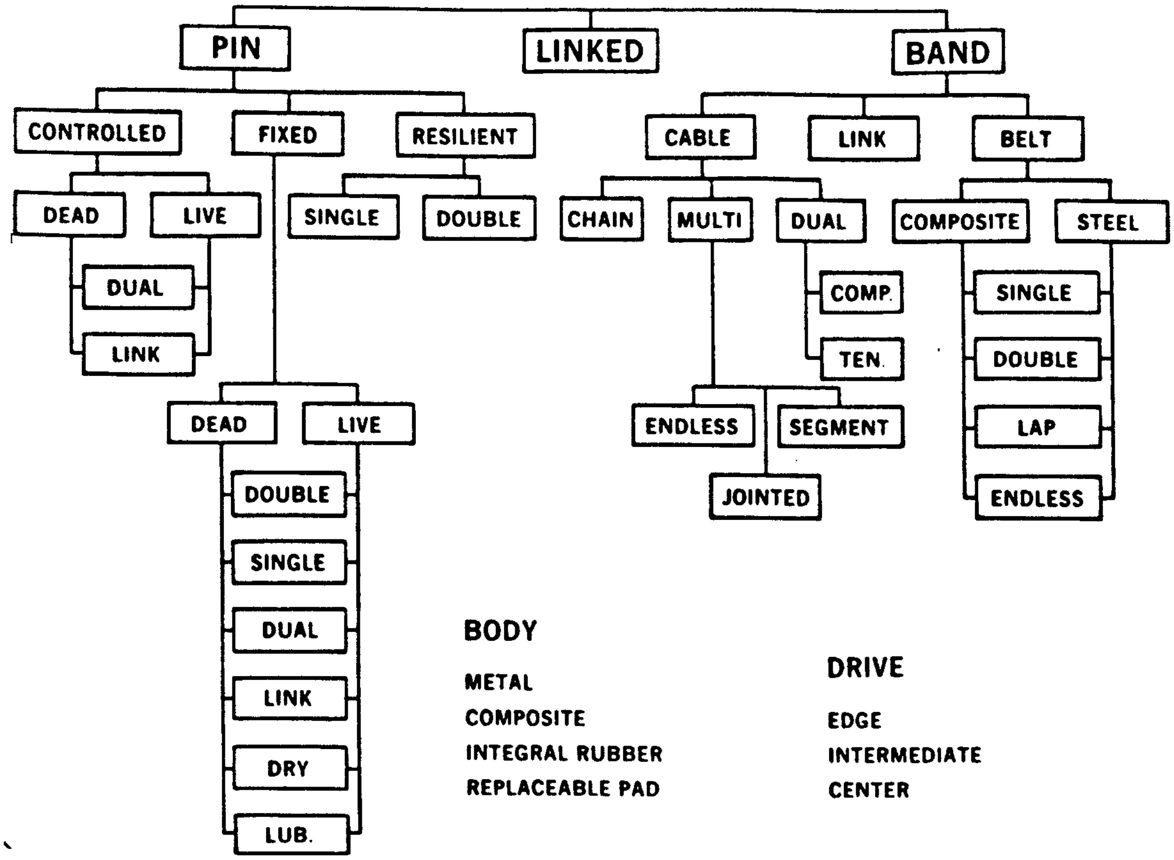

Figure 3-3. Track Types

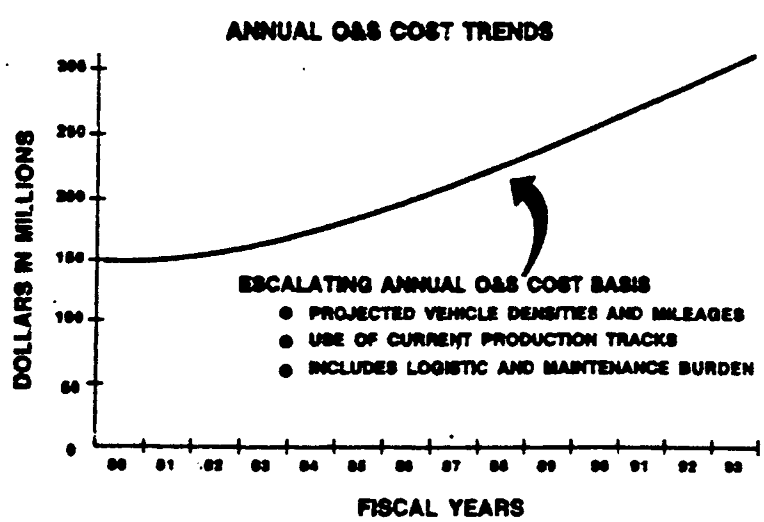

Figure 3-4. Track Repair and Replacement Cost Trends

3.1 Double-Pin, Replaceable-Pad Track

An obvious symptom of the technological void in the mobility area is the escalating annual track O&S cost associated with the Army's combat vehicle fleet (Figure 3-4). This cost escalation is the direct result of continually reduced track service life experienced with the greater performance demand and growing weight of current combat vehicles such as the Abrams Tank System and Bradley Fighting Vehicles. The Abrams Tank, rapidly approaching 70-ton gross vehicle weight, uses a double-pin, integral-pad track design, which limits service life to that of the rubber ground pad. Bradley Fighting Vehicles are increasing from 25 to 33 tons vehicle weight and use a single-pin, replaceable-pad track design which becomes rubber bushing service life limited.

Double-pin, replaceable-pad track designs are being developed within the framework of weight classes of vehicle commonality for both current and future armored combat vehicles (Figure 3-5). A significant peacetime logistics savings and improved combat effectiveness and survivability can be realized through the interoperability of track designs within vehicle weight classes. The replaceable-pad track configuration is the most cost-effective design for peacetime operation and provides rubber ground pads for protection of road surfaces. The track body structure includes integral grousers in order to maximize tractive effort and allow operation without pads during both combat mission and winter conditions. This approach is also responsive to the next generation of armored combat vehicles concept of medium and heavyweight class common modular chassis development.

A double-pin, replaceable-pad track (T150) has been developed to replace the production single-pin, replaceable-pad track (T130E1) on the M113 Family of Vehicles. Currently in the Product Improvement Program (PIP) phase, testing of the T150 track at Yuma Proving Ground has demonstrated over 11,000 mile average service life, as compared to less than 5,000 miles for the production T130E1 track. The T150 track system (including new hubs and sprockets) weight and cost increases are negligible, with nearly 50 percent ($25M) annual O&S cost savings projected following fleet conversion.

Another double-pin, replaceable-pad track (T154) being tested on 18-25 ton vehicles will establish the cost-effectiveness of replacing three different current production replaceable-pad tracks. These tracks are the T132E1 single pin (M110 Self-Propelled Gun and M578 Recovery Vehicle), the T136 double pin (M108/M109 Self-Propelled Howitzers), and the T157 single pin (M2/M3 Bradley Fighting Vehicles). The new double-pin track is designed for 15-inch standard width application, and accommodates both 18- and 21-inch width requirements with extended end connector design configurations. Track weight and projected production unit cost increases are minimal, including new hubs and sprockets, where required.

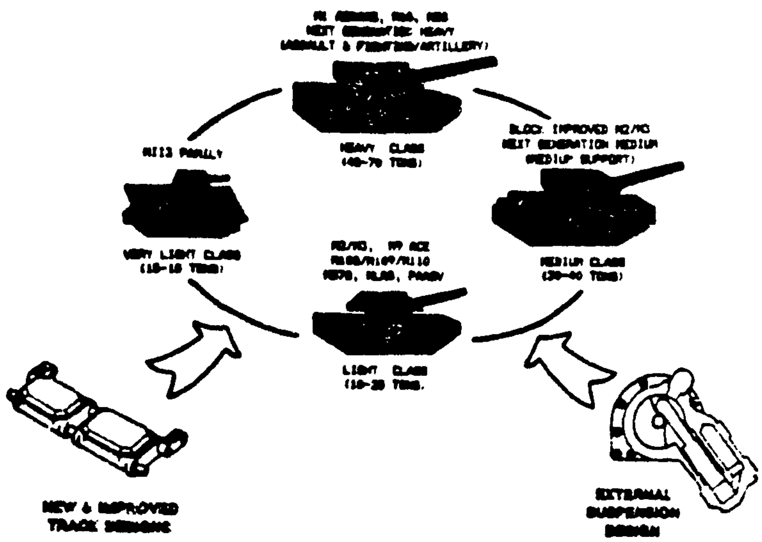

Figure 3-5. Weight Class Vehicle Commonality

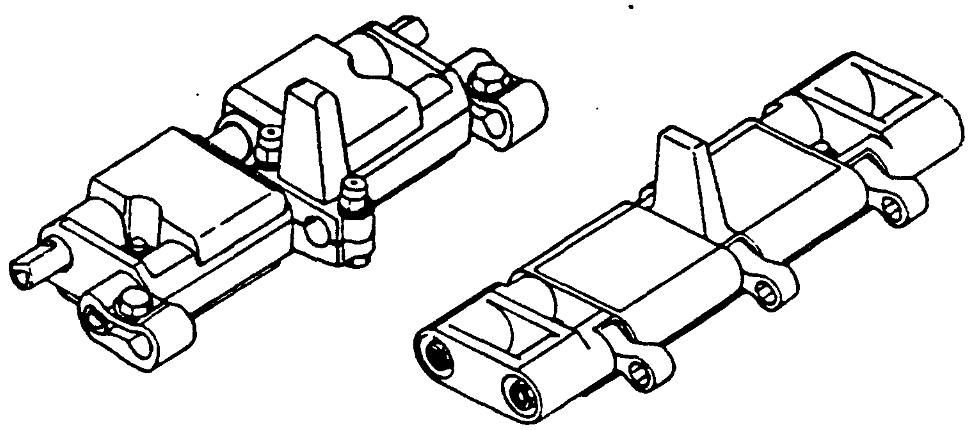

Figure 3-6. Next Generation Track Concepts

The potential for significant O&S cost savings is based on projected track service life ranging from 4,000 to 6,000 average miles, dependent upon individual vehicle system application.

The Abrams Tank System requirement for a 2,000-mile service life track is not satisfied by the 700-800 mile worldwide computed average of the standard production T156 integral pad track. A competitive production qualification test program was completed in early 1988 to determine the cost-effectiveness of replacing the T156 track with either the West German Diehl 570-N2 or FMC T158 replaceable-pad track system candidates. Although the Diehl track system demonstrated 5,510 miles mean service life, it increased track weight by 1.5 tons per tank, unit production cost increased 2.5 times, and its use required considerable tank modification (roadwheels, sprockets and support rollers). The FMC T158 track, which required no tank modification, demonstrated 2,100 miles mean service life with a track weight increase of 1.0 tons per tank and 2.1 times unit production cost savings over a 20-year economic study period. The FMC T158 track was selected as the most cost-effective system.

Several competing double-pin replaceable pad track design configurations are currently under development for the next generation of armored combat vehicles (Figure 3-6). There are also open solicitations to industry for potential new and innovative design and material technology applications. The technical design objectives address the need for combat-effective track configurations, which are also lighter in weight and provide longer field service life to reduce peacetime O&S costs.

Current efforts are directed at heavyweight (45-70 ton) class common chassis track development programs which are targeted for integration on the CATTB. Based on the proposed product improvements to the Bradley Fighting Vehicle, the gross vehicle weight is being pushed well into the medium weight classification for future combat vehicles. Anticipated inadequacy of the current production single-pin T157 track design at this higher weight is expected to heighten the necessity for medium (30-40 ton) weight class track development.

3.2 Improved Track Rubber

With greater vehicle mobility performance demands and system weight, the dynamic loads experienced by the track increase at an exponential rate. As with any system composed of component parts, track service life is dependent upon the life of its weakest component. Generally, the rubber components of any track design serve as this weak link. In the case of integral pad tracks, the wear of the rubber ground pad determines overall track service life and is determined by the wear of either the rubber bushing or the roadwheel path surface.

TACOM has been pursuing a comprehensive rubber technology development program aimed at increasing the service life of elastomeric track components through both design and material improvement approaches (Figure 3-7). Initiated in 1980, this effort has involved the leading experts from academia, industry, and other government agencies.

For the future, TACOM's principal role will be that of applications engineer with responsibility for laboratory and field vehicle test and evaluation for production suitability decisions. Efforts which will continue to be pursued at TACOM address developmental aids which can also serve as quality assurance tools in the form of field correlated laboratory simulation test equipment for track pad, bushing and roadwheel path rubber.

3.3 External Suspension (Hydropneumatic)

The current state of the art in high mobility suspension systems for tracked vehicles consists of the use of a torsion bar arrangement (Figure 3-1) to obtain the appropriate spring characteristics. Torsion bars are quite heavy and require considerable volume below the hull floor. The rotary spring characteristics of a torsion bar are quite linear, and the splined attachment technique precludes the use of any simple methods for equalizing the loadings under the different roadwheels.

Efforts have been under way now for several years to develop an external suspension system for tracked combat vehicles. The system would consist of independent Hydropneumatic Suspension System (HSS) units for each wheel station. Figure 3-8 depicts such a system integrated into the M1A1 vehicle. Maintenance for such a unit would consist of simply unbolting the unit in question and replacing it with a serviceable unit.

The physical characteristics of such a unit permits the realization of a wide variety of spring and damping characteristics that are conducive to the development of a very mobile vehicle. The static position of these external units can also be easily adjusted to provide more equalized wheel loadings. This, in turn, can improve the life expectancy of the roadwheels and tracks. The elimination of the torsion bars eliminates the requirement for internal hull volume to house the torsion bars and ultimately permits a vehicle with a lower silhouette to be designed. The replacement of the torsion bars and external shock absorbers with the individual external suspension units also offers the potential to decrease the total weight of the vehicle's suspension system.

Several competing designs for an HSS-based external suspension system are currently under development. Lab testing has already been completed on one of these concepts which is being designed for the heavy class (45-70 ton) of tracked combat vehicles. Two complete vehicle sets of external design are being fabricated for testing on the CATTB. Additional HSS external suspension concepts are also being developed as candidates on the ATTD and for possible retrofit on the M1A1 Abrams tank.

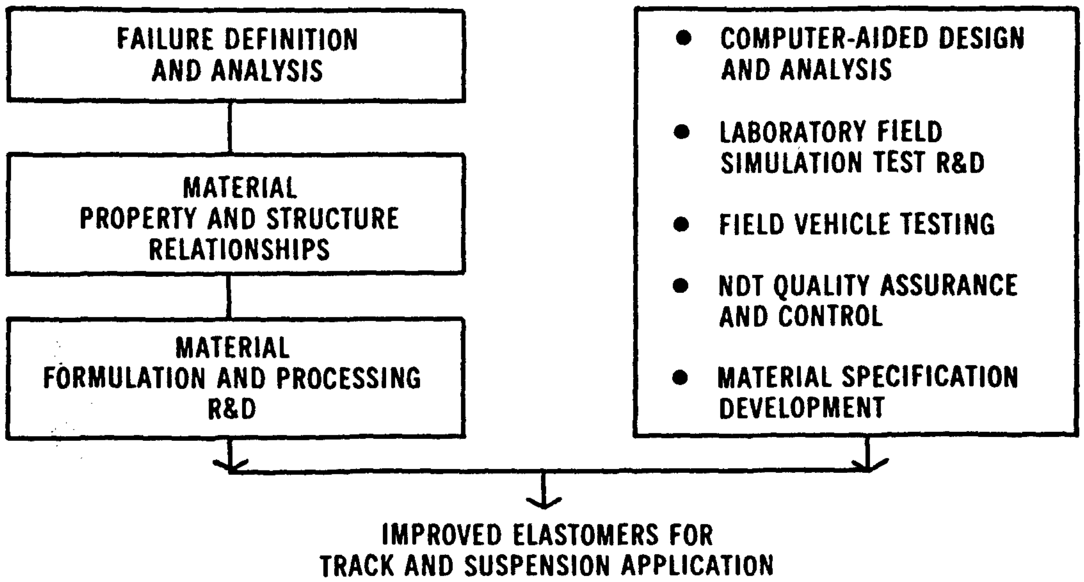

Figure 3-7. Track Rubber Technology

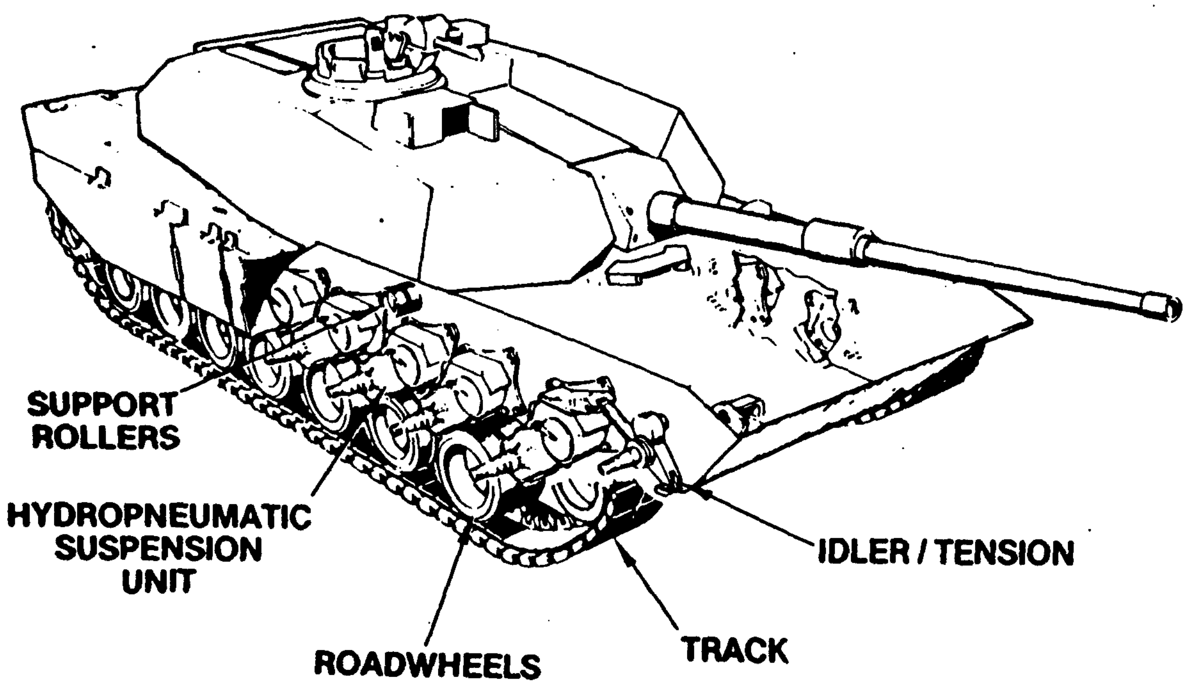

Figure 3-8. External Suspension System

The external suspension system concept is not limited to heavy combat vehicles. There is increasing interest in a similar suspension system design for the medium class (28-40 ton) of combat vehicles. Upweighting of the Bradley Fighting Vehicle continues to push it well into the medium weight classification of combat vehicles. The need to correspondingly upgrade its mobility and save weight wherever possible may necessitate a serious look at the potential gains offered by going to an external suspension system. The complete potential offered by external suspension systems cannot be realized by retrofitting the system to an existing combat vehicle, however. The reduced space claims on the internal hull volume can be fully taken advantage of only in a completely new combat vehicle design. In a new design, the armored volume can be appropriately reduced providing a lighter and lower fighting vehicle.

3.4 Adaptive Suspension

In future combat theater scenarios, mobility and agility are the keys to survival for tanks and crew. These increasing demands and the need for gun firing while in motion at high speeds that modern fighting vehicles need to achieve have necessitated that, in addition to automatic stabilization of the turret, the crew also has to be stabilized. The approach thus envisioned is to isolate the hull rather than individuals in chairs. This has the added advantage of isolating the electronic equipment and ammunition.

The principle of an adaptive suspension system is that the roadwheels of a tracked vehicle would follow the contours of the cross-country terrain more closely than at present and, with modern technology, isolate the hull platform as much as possible. This is now becoming feasible through the use of on-board microcomputers which control the devices supporting the hull. Microchip electronics allows for fast filtering and integration of terrain and sensor data.

There are essentially two kinds of adaptive suspensions of interest to the Army: fully active and semiactive. A third type of adaptive suspension, where the driver sets a selection switch for the degree of damping in the shock absorbers, is not of interest, because the emphasis in combat vehicles is on automatic control. Other than an experimental project at TACOM using Lord Corporation "on-off" damping, developments in adaptive suspensions have primarily been in the automotive field. There is some work going on in the British Defense Establishment on a tracked vehicle. Commercially, there are cars now available that have several settings for damping (soft, medium and hard). In some models, the setting is done automatically by a control unit. The setting is correctly made depending on road conditions. The data is constantly updated. Here, it is assumed the road conditions remain essentially the same for a long distance. Therefore, 30-50 inches of vehicle travel are allowed for change in damping. This is not the case for military vehicles where the cross-country terrain is constantly changing.

The Lord Corporation designed an "on-off" semiactive system. The hardware implementation of this concept was deemed a failure as their "on-off" shock absorbers could not perform adequately. It is conceivable that with the introduction of electrorheological shock absorbers, the development of an "on-off" semiactive suspension system for Army combat vehicles, can be successfully resumed.

In the meantime, the emphasis should be on obtaining available components for either a fully active suspension system using servoactuators in place of torsion bars and shock absorbers, or a limited active suspension system using hydropneumatic struts in which electromagnetic valving, controlled by a microchip computer, allows development of the most ideal spring and damping forces in each strut at each instant of time. In either case, it would require a forward looking detection device to sense the upcoming terrain undulations. Roll and yaw changes would be detected by rate gyros that would feed the information into the microchip controller, which, in turn, would make adjustments into the suspension support devices by valving adjustments.

It is conceivable that, with the implementation of adaptive suspensions into military vehicles, ground speeds could increase 25-50 percent and thus greatly contribute to mobility of ground vehicles in combat. This has been the indication with computer simulation studies performed by Oakland University.

3.5 Track Tension Adjuster

The function of a track tension adjuster is to maintain, for all mobility scenarios, a track tension which is relatively uniform and of the lowest possible magnitude while providing proper guidance of the track throughout its entire path. The track tension adjuster should maximize track and running gear life; aid in minimizing rolling resistance which, in turn, should improve drive train efficiency; assure a high level of mobility during an aggressive and/or high-speed maneuvering situation; and, in general, enhance the combat readiness, reliability, and maintenance characteristics of the vehicle over its life cycle.

An analysis of the present system indicates the need for another method to adjust track tension. Presently, the tension is adjusted on the M1 vehicle by the "Grease" method: the operator pumps grease in the track tensioner, which includes a pop up valve. The valve pops up at 3000 PSI which indicates that the track has been tensioned. It is unrealistic to expect that this adjustment is supposed to be adequate for all types of vehicle operations. Tracks usually loosen with time, thus resulting in a tendency for less retention. On the other hand, tensions are sometimes set excessively high to assure track retention, but high track tension causes premature idler, track, and sprocket wear and adversely affects performance.

In 1982, the U.S. Army Tank-Automotive Command (TACOM) commenced work in developing an automatic track tension adjusting system that meets the requirements and specification for the M2 and M3 vehicles. Two semiactive track adjusters have been built as a result of the above-mentioned effort. These units have been successfully tested for pressure leaks in the laboratory.

The government is currently pursuing two different approaches to obtain a dynamic track tension adjuster in order to upgrade the current M1A1 track tensioner system. The first approach is to modify the current system used on the British Army Fleet of Chieftain vehicles to fit on the M1A1 vehicle. The current Vickers Hydraulic Track Tensioner (HTT) device applies tension to the tracks via a double-acting ram. Adjustment of this system is accomplished from inside the driver's compartment by either electrical or mechanical pumps. Hydraulic pressure is locked inside the cylinder assembly during normal vehicle operation, and no running induced pressures are seen in the piping system inside the vehicle.

The second approach being pursued by TACOM to develop an advanced capability track tensioning system is to competitively solicit industry for possible concept designs. The resulting tensioner system should improve survivability, RAM-D, and fit with the current Abrams Tank suspension envelope. This system should function with hydropneumatic and torsion bar suspension systems and operate in either a driving, braking, forward or reverse mode. Also, a failure of the dynamic track tensioner should not disable the vehicle.

With these two approaches, it is anticipated that a satisfactory solution will be found to the track tension adjuster problems.

4.0 SURVIVABILITY

Vehicular survivability technologies are critical, because the United States faces increasingly hostile and aggressive adversaries. In virtually all areas of military weaponry, the U.S. is outnumbered by comparable opposing vehicles which are becoming increasingly capable. In this environment, U.S. military vehicles must achieve enhanced survivability through design provisions, which reduce susceptability and vulnerability.

The future battlefield environment will include conventional, chemical, biological, nuclear, electronic warfare, and directed-energy threats. Survivability against these threats can be enhanced by reducing the probability of being detected; if detected, reducing the probability of being hit; if hit, by reducing penetration with improved armor; and, if penetrated, reducing internal damage and increasing the capability of being rapidly repaired. Emerging technologies in these areas will be discussed in the following paragraphs.

4.1 Improved Armor

The two principal types of armor-piercing ammunition are the kinetic energy (KE) penetrator and the shaped charge. The KE round is a solid penetrator fired at very high velocity by high-pressure guns and relies solely on KE for penetration.

The shaped charge ("hollow charge") combines a copper-lined cone and a high-explosive (HE) charge embedded in a cylinder. Upon hitting the target, a fast fuze detonates the HE charge, and the high-pressure detonation wave squeezes the liner into a long jet travelling at speeds as high as 8 KM/sec (4.97 miles/sec). The jet impinges on the armor target, generating pressures which are greater than the yield strength of the armor. The jet acts on the armor steel and forces it to flow.

Defeating these types of ammunition has been a major R&D problem for many years. In many cases, materials that defeat one threat are ineffective against another threat.

In order to defeat the ever-improving threat, it has been necessary to explore materials and methods other than the traditional monolithic materials such as steel and aluminum, which have been the bulwark of armor vehicle construction in the past. Programs continue to improve steel and aluminum armor performance, since these materials will continue to be the structural material of choice for the foreseeable future. However, for significant gains in armor protection with minimum impact on weight, new materials and threat-defeating systems are being developed. Programs are being pursued to establish the armor capability of composites and ceramics. A composite turret has been produced and successfully tested.

Two programs are in progress to demonstrate the potential of composite hulls. Ceramics have been shown to have exceptionally good armor characteristics. How they may be employed in vehicle construction, faced with their poor structural properties, is being explored in a number of programs. Reactive armor technology has been evaluated and has potential.

In addition to the development of armor materials/systems, TACOM has the role of integrator. This involves the adaptation of unusual and complex armor systems into a vehicle structure in a producible and cost-effective way. In support of this activity, TACOM's armor group has sponsored and worked on the development of a number of armor models to enable the vehicle designer to rapidly establish the adequacy of a design or identify the material thickness he must incorporate to achieve a required level of protection. Also in support of the design integration, TACOM has developed an armor database which, when fully implemented, will enable the designer to identify and compare armor materials/systems that may meet his requirements. Further development of design support models is an ongoing effort.

4.2 Advanced Cast Armor (ACA)

ACA is the title of a TACOM Manufacturing Methods and Technology (MM&T) project initiated in FY85. It began as a combined TACOM/Rock Island Arsenal (RIA)/Ballistic Research Laboratory (BRL) effort and has expanded to include the Materials Technology Laboratory (MTL), the United States Marine Corp (USMC), Aberdeen Proving Ground (APG), the Bureau of Mines (BOM), and Los Alamos National Laboratory.

The objective was to use advanced casting technology, such as the "Lost Foam Process" (LFP), to produce complex armor designs in high-strength alloys. The BRL P-900 applique armor has been a total success, i.e., best protection, lightest weight, and lowest cost. The success of the ACA program prompted a structural/armor program sponsored by TACOM's RDE Center, to reduce the structural weight by at least 30 percent.

The structural designs developed by the RDE Center are pyramidal on semihoneycomb types that can only be produced by advanced casting processes. The finite element analysis indicates as high as 60% weight reduction. The RDE Center targeted structural components, because they have the highest potential for weight reduction, i.e., 38% of M1 weight is structural.

Also, BRL and Los Alamos National Laboratory are incorporating armor ceramics that are contained and confined by these advanced structures, which should produce a synergistic effect for the structural/armor concept. In addition, the technology developed by government labs has and is being transferred to industry.

Our government labs have led the way on cast armor via LFP, because industry was hampered by hardness problems (machinability) which, in our case, actually improves ballistic performance.

4.3 Signature Reduction

Combat vehicles are being detected by the threat at standoff ranges beyond our effective counterfire and are being targeted at vehicle locations with minimal armor. Reducing vehicle signatures, without adding encumberances, will decrease long-range detection and identification of U.S. combat vehicles, thus decreasing susceptibility to target acquisition systems, threat sensors, seekers, and associated munitions. This will improve combat vehicle crew survivability, scout and reconnaissance capabilities, as well as intelligence gathering. Thus, integrable, durable and effective electromagnetic, acoustic and seismic low-observable vehicle signature suppression materials, coatings and design techniques are required.

In order to do this effectively, validated computer models would aid in the design and evaluation of these techniques. The model would be used for processing measured signature data, generating data on proposed vehicle designs, and evaluating the performance of signature modification and suppression devices. The thermal/infrared vehicle signature model provides temperature data on a faceted representation of the surface of the vehicle to be modeled.

Techniques are being developed to modify the vehicle image and reduce its probability of detection, recognition, and identification as a potential target. Infrared and visual perceptibilities of various concept combat vehicles are being analyzed. This analysis includes thermal modeling and optical measurements through rain, fog, and snow. Simple measures, such as a smaller silhouette, will reduce a vehicle's profile on the battlefield and therefore its visual detectability.

The high-technology sensor systems of the future battlefield will necessitate that commanders rapidly block or screen their vehicles from these threats. Infrared decoys and smoke can assist field commanders in managing the signature of their vehicles to minimize detection. The technology focuses on smoke and obscurants that are effective in aiding deception on the battlefield. Technology exploration includes infrared screening compositions, atmospheric effects, multispectral screening compositions, infrared emissive smokes, aerosols to protect against high-energy lasers and high-power microwave weapons, advanced dissemination concepts, smoke elimination concepts, real-time obscurant characterization, and nontoxic smoke/obscurant. Rapid dispersal devices necessary for the multispectral screening smoke/obscurant will provide countermeasures to react quickly to homing munitions employed by the enemy.

Just as signature reduction would be used to reduce its probability of detection by an adversary, signatures could be used to detect an adversary vehicle. For example, a system may be able to detect and identify both friendly and threat ground vehicles. The system may also be able to provide information on the speed and bearing of the other vehicles.

4.4 Hit Avoidance

The hit avoidance program is devoted toward systems that enable the modern combat vehicle's increased threat detection capability coupled to advance countermeasure devices to react when the vehicle has been detected by a threat. The major effort in the hit avoidance program is the vehicle integrated defense system, which will provide increased survivability for new and existing vehicles through development and integration of:

- nonimaging, laser Identification Friend or Foe (IFF) and millimeter (MM) wave sensing/Artificial Intelligence

- crew interface and display by data management software

- programmable dispenser, projectile defeat and semiautomatic counterfire countermeasure reactions.

The threat of top attack munition will be minimized through integration of an active protection system. The object of such systems is to increase the crew ability to fight a multiple threat effectively without being overcome by the complexity of the situation. Compatibility to the Standard Army Vetronics Architecture is being designed in for complete integration to the vehicle electronics, including buses and displays. Several DA/DOD programs are being supported by this hit avoidance technology such as FOG-M and Chicken Little.

4.5 Protected Vision (Directed Energy Hardening).

All combat vehicles have a requirement to protect the crew and components from eye damage by laser radiation from ruby and nd:Yag laser rangefinders and designators. The initial requirement to protect only magnifying optics (sights) was expanded to cover all vehicle optics, including unity vision periscopes/vision blocks.

Unity vision devices have two general characteristics which influence the choice of protection technology: a) wide field of view, and b) relatively high-luminous transmission.

Results of protection technology investigations by TACOM led to the integration of several promising filter candidates with currently fielded unity vision equipment. This effort produced hardware using multilayer dielectric, absorption, and holographic filters.

A new filter specification and revised unity vision equipment drawings being released to the vehicle program managers will lead to incorporation of the unity vision ocular hazard protection filter in all combat vehicles. Contractor-supplied filters are also being tested to assess their conformance to current requirements.

Additional research and development is also under way in the areas of advanced multiline and broadband filters. Emerging threats will require new solutions including improved discrete wavelength filters and nonlinear materials with broadband response. Present activities include development of narrow notch holographic filters for use in the visible wavelength region, proof-of-principle demonstration of a broadband coherence filter, and fabrication of a laboratory test bed for evaluation of nonlinear materials. The advanced holographic filters will undergo comprehensive testing and will be integrated into unity devices immediately following such testing. Other work will concentrate on the expansion of efforts in the broadband filter arena and identification of promising approaches. Integration of broadband protection technologies into unity devices will be initiated if the development phase is successful.

5.0 VEHICLE ELECTRONICS (VETRONICS)

Electronics and communication equipment will be reduced in weight and volume through the use of Very High-Speed Integrated Circuits (VHSIC), thin film electroluminescent (TFEL) multifunction (MF) displays, the integration of communications, navigation, and identification equipment, hybrid processors, etc. There are ongoing efforts to downsize electronic components, while increasing their capability. There have been and will continue to be great strides in this area as these technologies advance, particularly in Very Low-Speed Integrated Circuits and other electronic devices that will contribute to improved mobility through lighter weight and low prime power sensors mounted on combat vehicles.

Miniaturized electronic components will be used to develop a vehicle integration architecture that will more efficiently integrate the vehicle's electrical/electronic systems. Just as avionics integrates an aircraft's electrical/electronic systems, Vetronics will provide the foundation for total system integration of all future combat vehicles. Combat vehicles have had several electrical subsystems added as a part of the design process. As these subsystems are being added, the required power supplies, wiring, etc. are also added. Rather than adding these subsystems one at a time, it would be more efficient to optimize electronics in a systemized manner. This would entail optimizing the computer architecture between the subsystems through an interface that enables them to share sensors, information, and power supplies.

Vetronics integration will provide an intelligent soldier-machine interface to optimize crew/vehicle effectiveness. It will also provide the key to increased supportability; reduced crew size; improved reliability, availability, and maintainability (RAM); and real-time integration with the electronic battlefield. This will allow more common sensor applications on a single vehicle, as required by the user. By eliminating as many components as possible, the electronics are made more reliable. Combat vehicles of the future are expected to have on board a "smart" system using microprocessors that enable the vehicle to monitor its own subsystems, communicate with the outside electronic battlefield, and perform selected automatic functions without crew intervention.

5.1 Multiplex Circuitry

To manage or handle increasing amounts of information at very high speeds, multiplex circuitry will be used. It employs identical, simple, relatively dumb transceiver units which communicate at a low data rate over a bidirectional bus with a microcomputer master controller. A bus is a conductor or an assembly of conductors for collecting electric currents and distributing them to outgoing feeders. By controlling and managing a multiplex wiring system with a microcomputer, new and old features which require costly hardware can be implemented in software at minimal cost.

This multiplex system would be a wired version developed for remote control of vehicular electrical loads. It would use identical multichannel transceivers at various nodes in the vehicle to accept switch or circuit inputs and to output signals for control of indicators, actuators, lights, engines, or other loads. Although the transceivers do not communicate with each other and have no knowledge of each other, the system would allow many transceivers to share a common bus. The choice of the specific wiring configuration linking the transceivers with the master controller involves tradeoffs among system response time, bit rate on the bus, wiring complexity, and required microcomputer performance. The extent to which load control switching should be grouped involves tradeoffs between wiring simplicity, system complexity, and overall costs.

Multiplexing has the potential to be cost-effective by partitioning automotive wiring so that blocks of transmitters and receivers can be grouped at convenient locations in the vehicle. This arrangement minimizes system wiring, as only a single bus is needed to service a large area of the vehicle from the centrally located master controller. The buses are bidirectional ones over which the master controller transmits to, and receives from, the transceivers. Remote transceiver units communicate with each other only through the master, even when transceivers share a common bus.

The master controller acts as the interpretative and authoritative link between switches or detectors, and loads or actuators. Switches and loads are not directly linked for reasons of safety, convenience, and system flexibility. Requests are intercepted by the microcomputer master, and may be ignored, passed on as a command, or interpreted as to the specific command to be issued. In addition, the microcomputer master controller can issue or cancel specific commands as a function of other inputs or states. As an example, the master controller could be used to control fuel delivery, spark timing, idle speed, and other engine characteristics.

Switch or circuit activation of a remote transceiver input will result in a request being sent to the microcomputer for verification, determination that the requested action is allowed (given the vehicle's present status), and interpretation. Following these checks, if the request is valid and permitted, the master sends a command on the bus to the appropriate remote transceivers to execute the desired action. Requests may be sent on a continuous or momentary basis.

A software latch or timer provides continuity for long-term or timed operation of electrical loads when the request is not transmitted each frame. However, commands by the master controller are sent on a frame-by-frame basis for as long as the action is desired, or the situation is valid. Request and command have significance because of the system's structure. A request may not result in the issuance of a command, and the actuation of a given request signal can result in different actions being taken as a function of systems or control status.

Remote transceivers of this multiplex system do not have, or require, decision-making ability, since system intelligence is to be concentrated in the master controller. Choice of a microcomputer as master controller allows concentrating resultant system complexity in the master controller's software. This strategy minimizes system cost by reducing complexity of the remote transceiver design and the wiring of the input switches. It also allows features to be modified or added by changing the programming of the system Read Only Memory (ROM), the space of the controller's memory where permanently stored software is kept. The programs in ROM are called firmware, because they are more permanent than software.

To manage the multiplex system effectively, the microcomputer master must perform two fundamental tasks: State-sequencing logic and real-time bus control. State sequencing is a software approach which cycles through various tables to determine whether the proper conditions exist to advance from one state to the next. It is the determination of each system output based on the history of system states related to that output. The technique is powerful and flexible, since the tables can be easily modified to effect changes in signal polarities, state relationships, and variable assignment.

Bus control requires the master controller to manage activity on the buses and control all timing functions. Bus control is provided by an interrupt-driven bus management scheme with timing for automotive functions. Since all timing can be provided centrally, all electromechanical and electronic timers can be eliminated from the vehicle.

Electrical multiplexing has its problems, particularly from electromagnetic interference (EMI). Optical multiplexing is not bothered by EMI. However, a conversion from electrical to optical and back again to electrical is required.

5.2 Optronics (Optical Energy Circuits)

Bell Laboratories is a pioneer in Optronics, in which optical energy is used in place of electrical energy. This removes the need for conversion to and from electrical. There will someday be a material that can handle optical bits, just like silicon integrated circuits handle electricity. When optical energy is processed, the signals travel at the speed of light. Rather than using the transistor of today, the new device will provide a switching function optically.

5.3 Fiber Optics Technology

Available space for the use of additional equipment in vehicles is decreasing. To address this problem, fiber optics systems are under development to replace conventional electrical wiring systems.

The conventional wiring harness uses circuits that require adequate Electromagnetic Interference (EMI) shielding. This causes the harness to be thicker, more costly, and requires higher connector reliability. These problems can best be solved via a fiber optic system to replace the single wire transmission line. One of the major advantages of this type of system is noise immunity, with EMI shielding limited to power supply and input/output lines only. Circuits can therefore be reduced in size if EMI shielding is not required. The optical fiber is free from "cross-talk" from nearby wires and can be located within a wire harness without experiencing EMI.

The two items which make up a complete fiber-optic system are the optical fiber and fiber-optic connector. The optic connector should be easy to handle and install as well as reliable under the vehicle's operating conditions. In the basic fiber-optic system operation, a Light Emitting Diode (LED) converts the electrical signal into an optical signal which is transmitted through the optical fiber. The receiver converts the optical signal back into an electrical signal via a photo transistor. The fiber must be as strong and flexible as conventional electrical wire. The connector must have the same mating and unmating characteristics as a conventional electrical connector used in a wire harness.

A typical optical fiber may consist of an acrylic plastic core with a Teflon coating and a polyethylene jacket. This fiber has the same characteristics as that of an electrical wire in a conventional harness.

5.4 Flat Panel Technology

Vacuum fluorescent (VF) technology has been advanced by the development of planar (flat, level surface) construction using a glass substrate (base) with a printed film about 10 microns thick (one micron is a millionth of a meter). Very fine display patterns using one micron films are also under development. These films have enhanced brightness and resolution for graphic displays such as vehicle dashboard displays or other information systems.

5.5 Laser Threat Detection

The requirement for laser warning receivers (LWRs) stems from the ever-increasing military deployment of lasers for range finding and target designation. The narrow beam width of the laser, high-energy efficiency, and semicovertness are distinct advantages to the deploying force. The lasers used are comparatively low in energy. Detection of illumination by a laser warns tanks and other targets of the probable arrival of a round, bomb or missile. Timely detection of energy laser activity by combat vehicles using LWRs offers the potential for evasive action, deployment of smoke/obscurant screens, or counterfire.

Considerable developmental work is being conducted in the area of LWR's with high-accuracy, direction-finding capability. The most commonly encountered laser systems used for rangefinding and target designation are based on ruby Neodymium (Nd) and carbon dioxide (CO_2). The CO_2 laser, operating in the infrared region, is able to penetrate rain, haze and smoke better than older visible and very near infrared systems and also has the benefit of being eye-safe.

LWRs should provide a high probability of intercept for laser threats of various wavelengths, while maintaining a low false alarm rate. The LWR must obtain enough data about the threat (wavelength, frequency, etc.) to identify it and enable use of countermeasures. The sensor heads of the LWR collect the laser illumination which is routed to the microprocessor unit by fiber optic cables. The signals are then processed and the crew alerted with an audible alarm and a visual indication of the threat bearing.

In another type of laser warning system, the LWR's sensor heads are incorporated with a warning receiver able to detect emissions from search, tracking and fire-control radars. This system is designed to warn armored combat vehicle crews of any threat from active enemy target-illuminating or acquisition systems and protect the vehicle by activating appropriate countermeasures, thereby improving vehicle survivability.

5.6 Laser Navigational System

The present method of finding the position of a vehicle on a terrain map relies on radio signals from a network of earth satellites. However, enemy countermeasures can jam these signals.

A jam-free system under development consists of an eye-safe laser range finder and a computer containing digital terrain map data. The vehicle operator uses the laser range finder to measure the distance between the vehicle and any three surrounding land elevations. These distances are determined by the length of time required for the laser beam to travel between the range finder and the terrain feature. This data is analyzed in a microprocessor and the vehicle positions located on a digital terrain map. Since the rangefinder and microprocessor are located within the robotic vehicle, enemy jamming efforts are defeated.

5.7 Integration of Propulsion System Controls

A single electronic module is now possible with microprocessor technology to provide improvements in performance, efficiency, signature, and fault diagnosis. This technology is contributing to an evolving capability to operate on a broad range of fuels.

Electronic fuel control systems and sensors to characterize fuel properties are being developed, along with supplementary systems to aid ignition. Through the investigation and generation of new technology in the key areas of microprocessor controlled electronic fuel injection, ancillary componentry modulation, sensors, new alternative fuel combustion processes, engine/fuel compatibility provisions, engine concepts for alternate fuels can be developed. This would allow for modification kits for engines in existing vehicles, in-production change for production engines, and incorporation in the design of new developmental engines.

5.8 Electronic Clutch Control (ECC)

The ECC uses only simple, reliable and low-cost mechanical linkage and components and requires no adjustment at the assembly plant or throughout the vehicle's life cycle. Since internal combustion engines cannot deliver torque at zero vehicle speed, a device is necessary to bridge the gap between flywheel and gearbox input speeds when the vehicle begins to move. Such devices have taken the form of manually operated dry clutches, centrifugal and electromagnetic clutches, hydraulic couplings and torque converter. Of these, only torque converter and manual single-disk dry clutches have been in vehicles over the last 20-30 years. They have been highly cost effective, reliable and easy to use. However, the torque converter exhibits constant slip even at high speed, with associated high fuel consumption. A manual clutch is rugged and inexpensive, does not slip, but is manually operated.

The electronic clutch control may eliminate the above problems. Using an ECC, the clutch could be made automatic, eliminating the conventional clutch pedal.

5.9 Technology Application

A resulting benefit of the above technologies will be a vehicle-integrated intelligence battlefield management system. The basic idea is to harness the combat data that can be used to advantage at the maneuver level, provide it rapidly via a tactical situation display that is electronically integrated with the unit commander, so that each weapon in the force can be employed efficiently.

6.0 ROBOTIC TECHNOLOGY

The sophistication and lethality of weapons in the world's arsenals today has placed the soldier at great potential risk. The expanding field of robotic technology can be used to reduce this risk and improve his survivability. Robotic devices can be used to perform specific mission functions in areas that would be hazardous to soldiers. The effectiveness of operations and efficiency are improved because of the elimination of such human factors as fatigue, fear and boredom. Personnel ceilings also make the prospect of automated crew functions, as well as fully unmanned vehicles, attractive.

The operation of weapon systems by remote control goes as far back as 1918 when unmanned, tracked vehicles with electric motors or gasoline engine propulsion systems were developed and fielded for mine-clearing operations.

In more recent years, robotic technology has contributed to the development of autoloaders and stabilized fire control systems found in combat vehicles today. Remotely controlled vehicles are a reality today and prototype vehicles have demonstrated the ability to breach minefields and obstacles. Unmanned robotic vehicles fall into two general categories. Remote control vehicles remove man from the vehicle but man is still involved in controlling the vehicle. Autonomous vehicles, on the other hand, remove the man from the control loop (at least partially) by making decisions based on available information. The information is obtained from the environment by sensors tailored to specific requirements.

In the future, robotic combat vehicles could be developed for reconnaissance anti-armor, logistics, and many other high risk or manpower intensive missions. Robotic manipulators could be used to expedite the ammunition handling procedure in rear areas, unloading pallets of bulk ammunition, or a host of dangerous tasks.

Although there is a great deal of potential for exploitation of robotics on the battlefield, much of the technology necessary is still very immature. Work is underway in government laboratories, private industry and academia to develop robotics technologies applicable to the future battlefield. The required research can be divided into the following categories: autonomous mobility control, communications, data transmission reduction (robot to controller), crew aids, mission package automation, and vehicle design. Work is underway and forecast in each of these areas.

6.1 Autonomous Mobility Control

The principal focus for development of this technology is the DARPA Autonomous Land Vehicle (ALV) program under which broadly applicable autonomous control algorithms are being researched and demonstrated. Image understanding, computer reasoning and land navigation research conducted under the program at various universities and private research companies is integrated into a mobile laboratory for periodic technology demonstrations.

Research in sensors, perception, reasoning, knowledge bases, control, vehicle characteristics, and the human interface are being combined to enable unmanned navigation in an unconstrained environment. ALV research will exploit advances in multi-sensor fusion, advanced computer architectures, and digital terrain data bases as well as future low cost, high accuracy inertial navigation systems. Such systems may employ ring laser gyroscopes and be updated based on laser scanning of the surrounding terrain. Although highly autonomous combat vehicles will not be fielded in the near term, opportunities for technology spin-offs for near-term applications are likely. Such applications are most likely to occur where the user is able to spot a specific role or niche that provides the robot a partially structured environment in which to operate.

6.2 Robot Communication

Robotic combat vehicles will always be controlled, at least to some extent, by humans. Therefore, some sort of communication link between the robot and its supervisor will always be needed. Current remote controlled or teleoperated systems require high bandwidth vision data in order to provide the operator with sufficient information with which to control the robot. Radio links for this application are not secure, require direct line-of-sight, and consume too much of the available radio bands on the battlefield. On the other hand, fiberoptic links do not have these problems, but may not be sufficiently rugged and are overly restrictive of movement on the battlefield. They are also subject to being easily interrupted by simply severing the link. Because of these inherent limitations, applications for teleoperated systems will be very limited. As robots become more autonomous, communications bandwidth requirements will be reduced. In some cases, robot communication will be possible over a low data rate, secure, non-line-of-sight radio link such as the Single Channel Ground-Air Radio System (SINCGARS). Other applications will require higher data rates than are possible over existing tactical radios. A SINCGARS type radio is needed in the medium bandwidth category. Such development is proposed but is not currently under way.

6.3 Control and Status Data Rate Reduction

Reduction in the quantity of status information and vehicle control commands will reduce the load on the communication system. The ultimate solution to this problem is the development of highly autonomous robots, but that will not happen soon. Work is under way to reduce the data transmission requirement with teleoperated systems. Data compression techniques are being applied to the video information used by remote operators. The amount of compression that can be applied without degrading the video image is limited, so other techniques are being explored. Two unique approaches currently being considered are Computer-Aided Remote Driving (CARD) and the Human Engineered Remote Driving System (HERDS).

CARD will provide a human operator with the ability to remotely drive one or more vehicles by designating an obstacle-free path in a three-dimensional display of images from widely separated stereo cameras onboard the remote vehicle. The designated path is transmitted to the vehicle for automatic execution. The vehicle executes the path by dead-reckoning navigation. This approach requires only one pair of images per designation cycle of perhaps 30 second duration. Conventional teleoperation requires 30 image frames every second for each vision channel. CARD offers the potential benefits of reduced operator workload as well as elimination of the wideband data links required for conventional teleoperation.

With the HERDS concept, single-image frames are transmitted from the remote vehicle to the control station at a rate of one frame every 3 seconds, instead of 30 frames per second, the normal video rate. Based on a knowledge of vehicle speed and steering changes, the fixed images are used to mimic continuous image transmission from the moving vehicle. The result is to reduce image data transmission requirements, while giving the driver acceptably realistic driving visibility.

6.4 Crew Aids

Robotics can also contribute to crew performance in conventional manned vehicles. One potential area of crew aids is automated route planners. These systems will determine the optimum route to a designated destination using a digital terrain data base, various heuristic search strategies, and input vehicle and mission parameters. Route planners are being developed that will select optimum routes based on cover and concealment, minimum time, minimum fuel, trafficability of specific vehicles, or any other criteria.

Future systems will also incorporate expert knowledge of combat tactics and enemy doctrine. Individual vehicle route planners could also be extended to battlefield planners which would aid commanders in mission planning.

6.5 Automated Mission Packages

Robotic combat vehicles will need to be capable of more than simply moving around the battlefield. They will be equipped with mission packages tailored to specific applications. The mission packages for future robotic vehicles will be either fully automated or be linked to a remote operator. Some of the likely missions suitable for robotic application are: antiarmor, reconnaissance, and logistic roles. A prototype mine field breaching system has been built and tested. The Robotic Obstacle Breaching Assault Tank (ROBAT) permits the operator to dismount the vehicle and control mine-clearing operations over a fiber-optic or radio link. The technology exists for other mission packages as well, such as antiarmor using an autoloader, automated fire control and the currently emerging automatic target recognition (ATR) technology. Other automated mission capabilities will be developed from industrial robotics (e.g., arms and manipulators) as hard user requirements are written.

6.6 Vehicle Design

Removing soldiers from combat vehicles offers several significant opportunities to the vehicle designer. With no soldiers on board to protect, armor can be reduced or eliminated. It may still be desirable to protect critical equipment on the vehicle, but the total volume requiring protection will be far less than for manned systems. Removing the soldiers also makes possible much smaller vehicles which will be less vulnerable to detection and attack. If the type of mission makes it desirable to have the robot appear to be a manned vehicle, it is possible to add a realistic shell to the robotic platform which presents many of the signature characteristics of the manned system, including infrared emissions and radar reflective characteristics.

Exploitation of these technologies is being accomplished by demonstration of new military capabilities to the user community in order to stimulate thought on what roles and missions can be better performed through the application of robotics. Once the user community understands the possibilities and considers innovative combinations of equipment and doctrine, new system requirements can be written.

The tool being created for technology demonstration is a robotic combat vehicle test-bed system comprised of a robotic command center (RCC) and several robot vehicles (RVs) which will operate under the supervision of the RCC. RCC is a tracked vehicle which will hold all of the equipment and personnel required to control four RVs. The RCC crew will consist of a driver for the RCC, plus three soldiers to control the RVs, one commander and two drivers.

As a test-bed, the equipment and capabilities will evolve as technology development permits. In its initial configuration, the RCC will possess the capabilities of conventional teleoperation, autonomous road following, and the baseline CARD capability. The system will also provide the operators with a route-planning capability and a means for controlling remote mission modules. RCC will be adaptable for controlling all future RV test-beds. The first robots to be paired with the RCC are modified Wiesel vehicles (small German tracked vehicles) and two different modified versions of the High-Mobility Multipurpose Wheeled Vehicle (HMMWV). These test-bed systems are the link between technology and field application.

7.0 SIMULATION

Different performance aspects of combat and tactical vehicles can be simulated by means of mathematical models or by special tests in the laboratory.

The interaction of the vehicle and its environment can be described by mathematical terms used to compute the vehicle's performance. Although the equations, in general, are extremely complex and the number of required computations is staggering, today's high-speed digital computers are able to execute mathematical models of increasing fidelity. There are many advantages to be gained from performing computer-based simulations.

First of all, one can examine many different design concepts before the metal is bent. This is in sharp contrast with the old "build-test-break-fix" approach where costly test-beds were built and tested. Naturally, only a small variety of design excursions could be examined before the days of computerized simulation. The results of applying this new methodology are a drastic reduction in development time and significant cost savings. Most importantly, optimum designs can be achieved because of the ability to "try" a wide variety of configurations.

There are problems which cannot be answered today by mathematical modeling and simulation. If the vehicle or the component subsystem exists, then one can either take it to a test track or one can conduct tests under well-controlled laboratory conditions. The latter provides more reliable results, usually in a shorter time, since the influencing factors can be systematically controlled by the test engineer.

7.1 Dynamic Computer Simulation

Vehicle dynamics simulation is used to examine the vehicle's ride behavior, determine its stability on the road or under off-road conditions, compute forces acting in joints or at any other critical position inside the vehicle, and study the effect of firing a combat vehicle's gun.

The currently used methodology is called Dynamic Analysis and Design System (DADS). The user has to input the individual elements of the vehicle, such as the hull or a suspension system. The computer then generates the simulation in the form of a system of differential equations, which are solved to yield the time histories of displacement, velocity and acceleration for any point of the vehicle. In addition to examining reams of output data, animated video tapes are created which display a "motion picture" of the vehicle operating under the conditions specified. These are extremely useful for grasping the problems and for discovering anomalies in the simulation which would otherwise go undetected.

7.2 Test Track Simulation

For many years, vehicles have been tested for endurance at a proving ground, using a driver and a test track to simulate driving conditions. New technology and developments in automated computer control of servohydraulic actuators have been combined to simulate the dynamic effects of the test track on vehicles and their components.

Laboratory simulation holds the potential for greatly accelerating testing time, reducing testing and manufacturing start-up costs, and ultimately producing qualitatively better test results and higher standards of quality for the vehicle itself by increasing repeatability and reducing uncontrolled variables in the testing process. Thus, testing dollars are more efficiently used.

Laboratory road simulation is becoming widely accepted because of several advantages. Bringing the test track into the test lab provides a relatively clean environment for introducing other analytical tools and engineering expertise to study various problems. The engineer can actually see and measure what is happening to the vehicle. For example, the engineer can observe initial part failure which cannot be done as easily on a test track.

A large library of typical road profiles exists at TACOM's System Simulation and Technology Division. For example, when a turret has to be tested in the laboratory, the servohydraulic actuators have to move the turret exactly as if it were part of the entire vehicle operating in the field. To this end, the vehicle is mathematically modeled, and the motion of the turret is computed. The output is converted to driving signals for the actuators which shake the turret as if it was part of the entire vehicle running over cross-country terrain.

7.3. Finite Element Analysis (FEA), Modeling/Simulation

FEA is a general, three-dimensional, structural response modeling and analytical simulation methodology which provides the capability for determining local deformation and temperature measures of performance for components of vehicle systems. A component is simulated as a collection of material fragments called "elements" which can elastically deform (flex) or conduct heat. Calculations are performed to predict deflections and temperatures of these elements and the corresponding distribution of stress within the component. The stress level is related to the strength and fatigue life of the component.

FEA can be applied to predict the following performance measures:

1. Structural response due to static loads
   a. Material deflections, temperature
   b. Stress and strain distribution
   c. Strain energy
   d. Reaction loads at component interfaces or attachments
   e. Buckling loads and modes

2. Structural dynamic characteristics
   a. Natural frequencies
   b. Modes of vibration

3. Structural response to dynamic loads
   a. Time histories of material deflections and temperature
   b. Time histories of stress and strain distribution
   c. Time histories of strain energy
   d. Time histories of reaction loads

4. Limiting structural loads, i.e., strength of components

5. Structural interaction between components

6. Attachment or joint connection performance and/or requirements

FEA has also been successfully applied to many structural problems at TACOM in the past couple years, including:

1. System performance specification development
   a. M939 Truck - torsional rigidity analysis
   b. MAN Truck - torsional rigidity analysis

2. Feasibility study programs
   a. ASTB - M2 Hull reinforcement to blast loading

3. Product improvement programs
   a. M1 - T158 track shoe structural integrity analysis
   b. M2 - T154 track shoe weight reduction
   c. M1A1 - Dynamic analysis of alternative main weapons
   d. M88A1 - Towbar clevis replacemnt

4. Field vehicle troubleshooting

   a. M110 - Engine cooling for rotor lock-up problem
   b. M88A1 - Towbar buckling analysis
   c. Trucks - Capacity rating of 10K, 20K and 45K winches

5. Detailed design

   a. TMBS - test-bed interface development
   b. Gun-Firing Simulation Fixture Design

7.4 Vehicle Production Simulation

Production simulation is a computer simulation or model of the manufacturing process (fabrication, assembly, inspection, etc.) which can be used to gain insight into the behavior of a system.

The use of production simulation can help reduce the Army's reliance on qualitative intuition and experience in defining and evaluating initial production facilities, depot rebuild facility operations, proposed modifications, and proposed new facilities. Other benefits include: a. Timeliness - with computer simulation, more accurate and effective decisions can be made in shorter periods of time than are presently possible. Additionally, time to plan and introduce new processes and equipment will be reduced; b. Accuracy - as a quantitative tool, simulation is more accurate than the manual methods now used; c. Cost Reduction - costs can be reduced by using simulation to perform a trade study in lieu of a pilot line, by completing parameterizations in shorter time periods, in order to obtain optimum results or range of results and by eliminating mistakes through simulation's increased logic of software and quantitative information over the methods now used.

Production simulation can aid in evaluating:

- expected system throughput
- equipment utilization
- effect of random equipment failures on manufacturing process
- bottlenecks
- necessary options, e.g., labor or equipment to alleviate bottlenecks
- plant capacity
- effects of reduction or surge in production
- developing and evaluating strategies for changeovers from one vehicle system to another and from equipment or process improvements
- assessing the results of opening or closing a plant
- developing and evolving strategies for integrating prime contractors with 2nd and 3rd tier subcontractors
- plans for macro/microsimulation models of tank-automotive Government-Owned Contractor-Operated (GOCO) plants
- supporting depots such as Anniston Army Depot

8.Ø INTEGRATION

Most current systems are a collection of components packaged together, without consideration for the optimization of space. However, the threat dictates that future combat vehicles be designed to package personnel and materiel into the smallest volume possible, which will allow them to accomplish their mission. There are many potential technologies that must be combined to create an optimized fighting vehicle. However, there are often integration problems that must be solved first, before the integrated subsystem or full system can be used effectively. Integrated programs which combine several subcomponents into a reduced-volume, highly capable subsystem (examples: Advanced Integration Propulsion System (AIPS), Vetronics, Multi-Target Acquisition System (MTAS)) are needed. Development efforts which determine the compatibility of components that must either work together or exist in close proximity (examples: Reactive Modular Armor and its structural container, or electronic equipment on a Directed Energy Vehicle) are also required.

9.0 MANUFACTURING

The manufacturing technology program investigates the latest technology and possible application to the manufacture of combat vehicles. Constant technology advances in processes, cutting tool technology, welding, computer control of processes, machine tools and material handling can be applied to existing combat vehicle designs or utilized in future vehicle development to lower production costs and produce quality components.

9.1 Electrostatic Welding

The welding of heavy armor steel plate has always been a serious manufacturing problem. Development work is being conducted on a patented high-voltage electrostatic field device that has the potential to improve the quality and lower the cost of heavy steel armor plate welding. The thrust of this work is to increase weld deposition rates with improved physical properties by providing a fine grain weld structure. This is done by controlling the cooling rate of the weld metal and heat affected zone. Benefits of this process are reduced hydrogen cracking, reduced weld joint cracking, and improved toughness of the steel being welded.

9.2 Composite Materials

Current high-strength composites are bonded with epoxy resins, which are thermosetting (nonmelting) resins. The matrix is permanently, irreversibly hardened when a chemical reaction occurs under heat and pressure, which is a costly, time-consuming process. Any major quality defect renders the part unusable, even as scrap, since it cannot be remelted. Thermoplastic materials are under development for turret and other applications. These materials have the advantage that they melt (become plastic) when heated and harden when they cool, and this process is reversible. Unlike thermosetting plastics that require curing, thermoplastics can be injection-molded into complex shapes, bonded with adhesives or ultrasonic welding, as well as repaired and reshaped.

9.3 Laser Heat Treating

With laser technology, both the location and the depth of the high-wear part area can be treated and controlled very precisely. There will be minimal distortion of the part due to the heat treating process. Approximately 5% of manufacturing costs can be saved due to reduced machining with an approximate 20% increase in the part's service life.

M2/M3 track shoes have been laser heated in the sprocket contact and center guide areas. Many other applications are foreseen in the near future.

9.4 Laser Welding

Manufacturing costs for the M1 Abrams turbine engine have been reduced by utilizing an automated laser welding system to weld the internal air passage hole joints in the turbine engine recuperator. A successful system was designed, assembled, tested, and installed that welds these joints faster and at less cost and also provides a higher quality weldment.

9.5 Laser Cutting and Drilling

Lasers are specified for specific applications, because they do not have any of the drawbacks normally associated with contact processes, such as tool wear while cutting or drilling. Lack of physical contact with the workpiece and precise control over the total heat input results in little or no mechanical and only minimal thermal distortion.

Flexibility is another advantage. One laser can be used to process different materials. By changing a few parameters, the same unit can effectively weld, cut, or heat treat materials. Being an electronically driven device, a laser can be computer-controlled.

Two types of lasers are used by the automotive industry. Gas lasers like carbon dioxide (CO2) have the versatility to process both metals and nonmetals. Solid-state lasers which are used in metalworking applications are neodymium-doped (Nd) yttrium-aluminum garnet (YAG) and glass.

The mode of operation, either pulsed or continuous wave (CW), is an important factor to consider in laser processing. In the CO2 laser, the maximum CW output power level equals the rated total power for a particular model of laser. When operating in a pulsed mode, the laser is electronically modulated to emit a pulse with an enhanced peak power several times greater than the CW power level. High peak power initiates rapid vaporization when the beam interacts with the work surface.

This burst of power is useful for drilling, cutting, and welding because most of the energy from the CO2 laser beam couples into the molten material without heating the surrounding area. The heat affected zone is typically less than 0.005 to 0.015 inches in metal thicknesses up to 0.375 inches. This is considerably less than cuts made with other thermal processes.

A Nd:YAG laser, like a CO2, can be operated in a CW mode. It can also be pulsed with a Q-switch which has the effect of a shutter moving in and out of the beam path. This creates a high-energy buildup which, when released by the Q-switch, creates a high-energy pulse.

These pulses are of very short duration, typically lasting 200 nanoseconds (200 billionths of a second). In this mode, repetition rates of more than 25,000 pulses per second can be obtained, although at these high rates, the energy per pulse is low, if compared with the output of low-repetition rate CO2 and flashlamp pulsed Nd:YAG lasers.

Nd:YAG and Nd:Glass lasers with energy per pulse ranging from 3 to 80 joules can drill holes through cobalt-nickel alloys to depths as great as one inch, as well as cut, spot weld, and seam weld.

Cutting small holes, narrow slots, and closely spaced patterns in many types of metals and synthetic materials is another widely used laser machining process. Cutting is essentially a drilling process where the laser beam is moved along a programmed path. Benefits include burr-free holes, precision location, no cutting tools to replace, no cutting chips, cost-effectiveness, and improved productivity.

9.6 Producibility

TACOM continues to support the DOD-wide thrust in enhanced producibility of tank-automotive material. The objective is to ensure the timely and cost-effective production of equipment, with acceptable quality. TACOM activities include a) command-wide management for implementation of AMC, DA and DOD policy, guidance and regulations; b) Command-wide advocacy of proactive philosophies such as concurrrent or simultaneous engineering from the outset of concept formulation through fielding and encouraging an "obsession with quality" to ensure "doing it right the first time;" c) contractual coverage for producibility activities early in the acquisition cycle in emerging major systems such as the Armored System Modernization (ASM) vehicles and major subsystems such as the Advanced Integrated Propulsion System (AIPS); d) In-house producibility reviews and analysis supporting RDE Center prototype and technology demonstration development programs; and e) continuing developmental training of TACOM personnel for both the administration of producibility activities and the active conduct of in-house producibility reviews and assessments. Continued emphasis will be on expanding the in-house capabilities for a greater active role in the conduct of producibility engineering and planning, including reviews and assessments of RDE tech base and proof-of-principle technology developments.

10.0 MATERIALS/COMPOSITES

Composite materials offer many advantages in advanced combat vehicle design. These materials are ideal for lightweight use because of their relative strength, stiffness, fatigue and damage resistance, corrosion resistance, and design flexibility. Because of their lower density and higher strength, composites offset higher initial costs. Molding advantages over machined metallic components greatly reduce production costs.

10.1 Composite Structure

The structure of composites contributes to their unique characteristics. Composites based on thermosetting plastic resins are interspersed with fibers of fiberglass, Kevlar, Aramid or other organic and inorganic materials to provide a high strength-to-weight ratio and maximum protection against ballistic threats. Some of the applications under current study include composite turret and hull, and lightweight howitzers for air transport.

Materials under consideration include fiberglass woven fabric impregnated with polyester resin for bonding, graphite fiber reinforced epoxy, and other materials. Ballistic evaluations have verified all the anticipated benefits of fabricating major ground combat vehicle structure components from composites.

10.2 Armor Materials

The word armor implies a material/system with improved ballistic resistance and covers a vast array, from protective clothing to combat weapons. The trend in armor development is toward lighter-weight equipment. Armor on these systems is no exception to the trend, in spite of increasing levels of threats. Technical developments in metals are concentrating on alloy compositions and improved processing techniques. Metallic armor programs include development of high-strength steels for combined hardness and fracture toughness, such as:

- Ultrahigh-strength steels.
- Armor plate with improved shattering resistance.
- Thick dual-hard armor steel.
- Textured steel for armor application.
- Improved joining (welding) processes.
- High-strength aluminum armor.

One new class of alloys being investigated for application to combat vehicles is an ultrahigh carbon steel. The 1-2% high-carbon content means these steels can be heat-treated to high hardness levels and permit easier rolling and bonding to themselves or other steels, and then can be selectively heat-treated. Crystal structure orientations can be controlled through thermomechanical processing. This provides improvements in ballistic and critical mechanical properties.

The use of aluminum armor on Army ground vehicles is extensive for reasons that include ballistic properties, light weight, ease of manufacture, and low cost.

Application of ceramic armor technology to ground combat vehicles has been limited because of high material cost and lack of structural and multiple-hit integrity. However, escalating protection requirements on current and future combat vehicles has renewed interest in ceramic armor. Some very promising ceramic armor candidates for combat vehicle application are emerging.

The use of organic materials for combat vehicle structure and components is being considered with increased interest. Lightweight composite armor systems, which include organic-based materials such as glass-reinforced plastic, are being evaluated.

Kevlar and glass-reinforced plastic-type materials have been demonstrated to be most effective for spall (chip or splinter) suppression liners within critical combat vehicle areas.

Composite/hybrid structures are replacing monolithic metals in many applications, including armor because of weight and cost reduction and improved ballistic capability. Lightweight composite armor made of steel, aluminum, and Kevlar has been optimized for kinetic energy penetrator and fragment application.

10.3 Metal Matrix Composites

Metal matrix composites comprised of high-strength reinforcing fibers locked in a matrix (base structure) of aluminum, magnesium, or titanium hold promise of performance advantages for lighter, stronger metals for vehicular applications. The physical and mechanical properties of the composite are a blend of those provided by the reinforcing fibers and matrix. The increasing use of low-cost ceramic fibers and a metal fabrication method called squeeze casting offers the possibility of making vehicular components economically from metal-matrix composites. Squeeze casting of pistons which have been ceramic-fiber-reinforced (CFR) provides superior resistance to wear and seizure, lighter weight, and significant improvements in engine performance and diesel fuel efficiency.

CFR composites add the following enhancements to many vehicular components:

- Increased strength, wear resistance, fatigue life and thermal insulation.
- Decreased thermal expansion and thermal conductivity.
- Decreased product weight.
- Lower product cost.

The primary method of production for metal-matrix parts made of CFR composites has been squeeze casting. In the basic squeeze-casting process, a fiber preform is held in the casting mold by a fixture. Molten metal is forced into the preform at a pressure of more than 1,000 psi, and then a higher pressure of 30,000 psi is applied. The fiber preform is quickly and completely infiltrated by the molten metal before it hardens, resulting in a fiber-reinforced part.

Other fibers under consideration for vehicular metal-matrix composite parts include carbon fibers, silicon carbide whiskers, and aluminosilicate ceramic fibers.

10.4 Advanced Ceramics

The potential for these durable, lightweight, high-temperature materials in diesel and turbine engine applications is enormous. Examples include exhaust port liners, turborotors, gas turbine engine blades, vanes, and combustors. The versatility of ceramics and their unique combination of properties make them key subjects for further development. They are lightweight and wear-resistant, excellent insulators, and are extremely strong at high temperatures.

Some ceramics are one-third the density of the most advanced super-alloys and one-half that of steel. This weight reduction makes them ideal for use in turborotors, valves, piston, and piston pins. Benefits obtained from the use of ceramic materials include improved engine response, speed and power, decreased vibration and better fuel efficiency.

A composite redesign of the gas turbine engine may be possible to take advantage of the unique properties of ceramics. Unlike in piston engines, all four phases of the combustion cycle occur in different sections of the gas turbine engine. Temperatures in each section are not averaged over the four cycles, but rather, can rise to the limit of design and material capabilities. The hotter the turbine runs, the more fuel efficient it becomes.

10.5 Corrosion Prevention and Control (CPC)

TACOM manages a number of programs in Corrosion Prevention and Control (CPC) designed to impact vehicular life cycle costs. Among the R&D programs are the following:

a. Two tests: (1) marine exposure testing at Cape Canaveral and (2) field testing in Hawaii, Panama, and Puerto Rico are being conducted to evaluate corrosion-resistant coating for application to the Tactical Vehicle Wheeled Fleet.

b. A Small Business Innovative Research (SBIR) contract sets up a Corrosion Data Base Management structure to track corrosion.

c. A recently completed Accelerated Corrosion Testing Program on the HMMWV will determine if 15-year designed-in corrosion protection is adequate and will identify life-cycle maintenance costs.

d. Corrosion Prevention and Control (CPC) requirements have been included in RFPs for system development contracts. Materials engineering skills have been established as a requirement for the M1 competitive STS contract.

In addition, TACOM has established Corrosion Prevention Action Teams (CPATs) in accordance with AR 750-59 to insure lessons learned are being applied to Force Modernization Vehicles. TACOM has updated the "Design Guidelines for Prevention of Corrosion in Tactical Vehicles," initially written in 1980/1981, to include combat vehicles. This updated version has been disseminated throughout AMC and is being well-received as a contribution to CPC for enhancing awareness of corrosion and in utilizing technology to reduce the overall cost of corrosion for TACOM equipment.

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24. "Positive-displacement Supercharging Raises Diesel Efficiency," Automotive Engineering, November, 1984.

25. "CVT Control Systems: Some Design Considerations," Automotive Engineering, October, 1984.

26. "Electronic Actuator Eliminates Clutch Pedal," Automotive Engineering, October, 1984.

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APPENDIX A

MAJOR TANK DEVELOPMENTS (CHRONOLOGICAL HISTORY)

YEAR	TANK
1918	- WW I Tank, (British)
1918	- Mine Sweeping Tank
1918	- Light Tank, (German)
1918	- Bridging Tank
1918	- Skeleton Tank, (US)
1918	- Ansoldo Wheeled Tank, (Italian)
Post WW I	- Chemical Warfare Tank
1919	- Christie Tank, (US)
1921	- St. Chamond Wheel - Track Tank, (French)
1924	- Renault Rubber Tracks Tank, (French)
1926	- Heavy Tank, 3C, (French)
1926	- Medium Tank, (US)
1927	- MS-1 Escort Tank, (Soviet)
1927	- Light Tank, T1E2, (US)
1929	- Carden - Loyd Tankette, (British)
1929	- Medium Victers Tank, (British)
1930	- T-24 Tank, (Soviet)
1931	- Vickers Amphibious 3-Ton Tank, (German)
1932	- Wheel-Track BT Tank, (Soviet)
1932	- Christie Tank, (US)
1932	- Light Tank T-26, (Soviet)
1932	- "Superfast" Christie Tank, (US)
1932	- Amphibious Tank T-37, (Soviet)
----	- Christie Wheel-Track Tank, (US)
1933	- 3-Turret Medium Tank, T-28, (Soviet)
1933	- Renault Tankette, (French)
1934	- Remote Control Tank, (Japanese)
1935	- Light Tank, PzKpwI, (German)
1936	- BT Tank, (Soviet)
1936	- 5-Turret Heavy Tank T-35, (Soviet)
1936	- Light Tank with Trench Crossing Tail, (French)
1939	- Matilda MKII, (British)
1939	- PzKpw III, (German)
1939	- PzKpw IV, (German)
1939	- Heavy Rheinmetall Tank, (German)
1940	- Light Tank T-40, (Soviet)
1940	- KV Heavy Tank, (Soviet)
1940	- Medium Tank T-34, (Soviet)
1941	- Light Tank T-60, (Soviet)
1941	- Sherman Tank M4A2, (US)
1942	- Churchill MK IV, (British)
1943	- Medium Tank, Panther, (German)
1943	- Tiger Heavy Tank, (German)
1944	- SM-122 SP Gun, (Soviet)
1944	- Medium Tank, Cromwell, (British)
1944	- Tiger II Heavy Tank, (German)

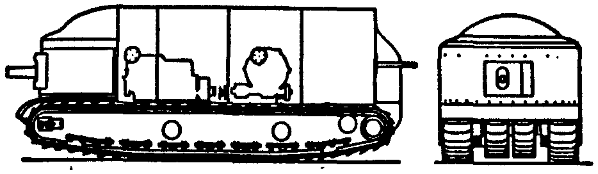
YEAR	TANK
1945	- Joseph Stalin Heavy Tank, (Soviet)
1946	- Pershing Heavy Tank M26, (US)
1950	- Heavy Tank M103, (US)
1951	- Medium Tank M47, Patton, (US)
1953	- Medium Tank M48, Patton, (US)
1956	- Heavy Tank M60, (US)
1980	- Heavy Tank M1 Abrams, (US)

Current (Soviet) - Heavy Tank T-72, T-80, FST-1 (Turretless under development)

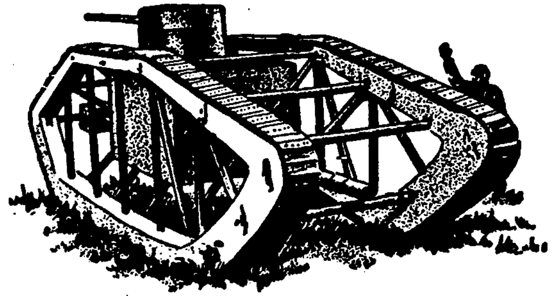
NOTE: All dates are approximate, first production dates.

APPENDIX B

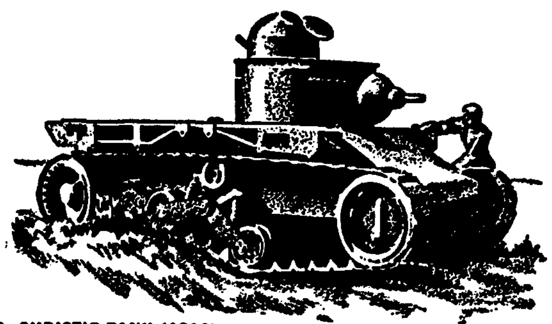
PICTORIAL HISTORY OF TANKS



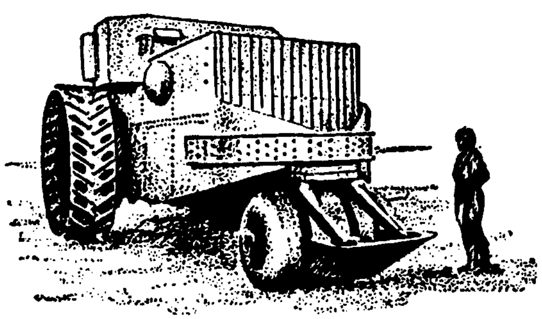
BRITISH "FLYING ELEPHANT" TANK, A 1916 CONCEPT FOR A 100 TON TANK WITH SUPPLEMENTARY TRACKS UNDER BELLY



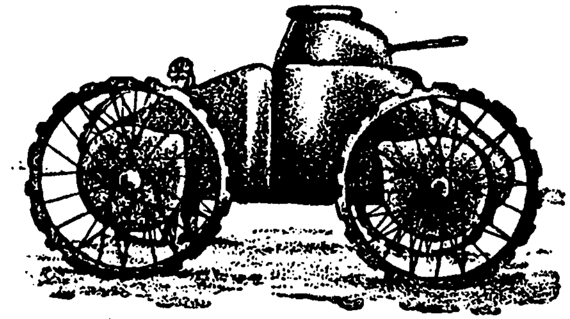
SKELETON TANK - A TANK OF THIS CONCEPT WAS CONSTRUCTED IN THE U.S. IN 1918.



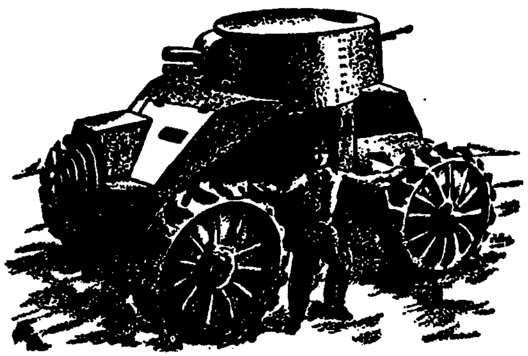
U.S. CHRISTIE TANK (1919)



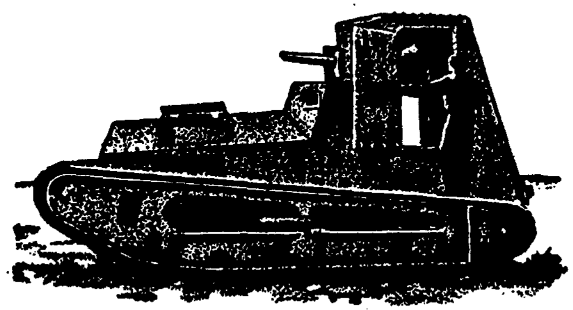
U.S. HOLT WHEELED TANK WITH STEAM ENGINE (1918)



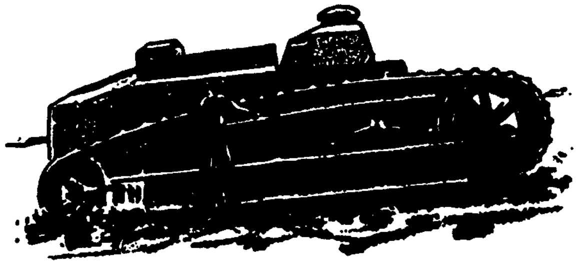
ITALIAN WHEELED TANK (PAVEZIA) (1918)

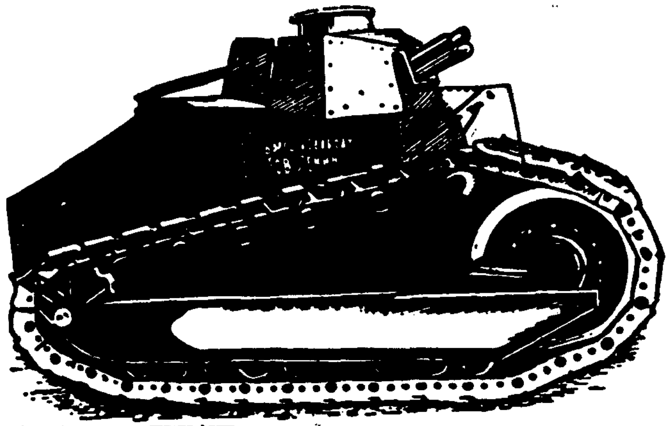


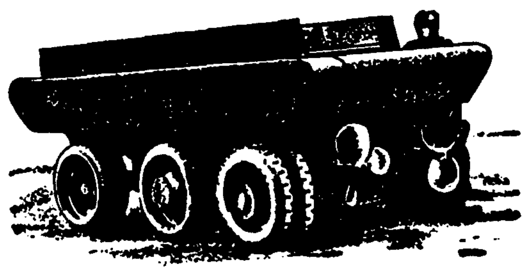
ITALIAN WHEELED TANK (ANSALDO), CIRCA 1918

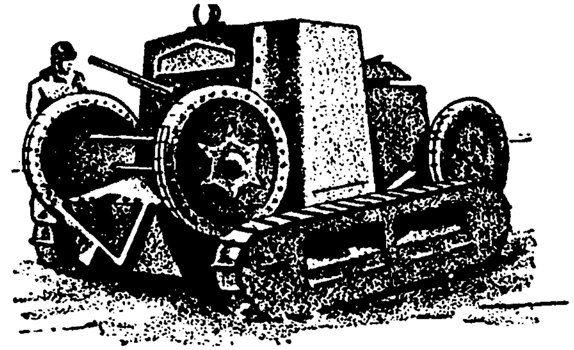


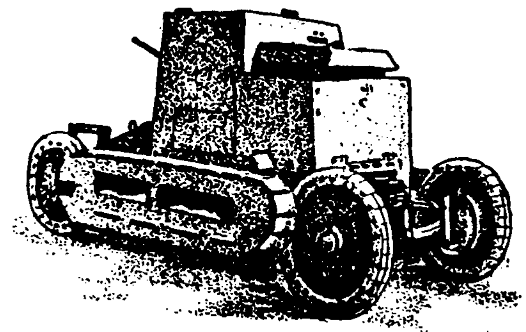
GERMAN LIGHT TANK LK-II (1918)

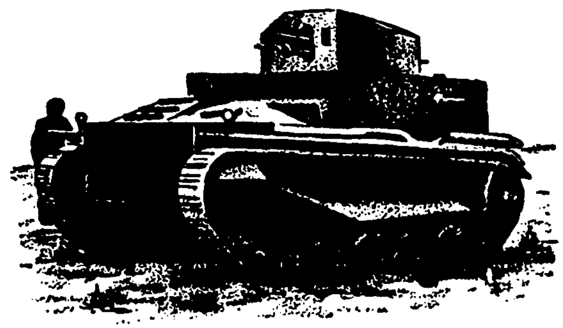

FRENCH MEDIUM DELAUNAY-BELLEVILLE TANK (1920)

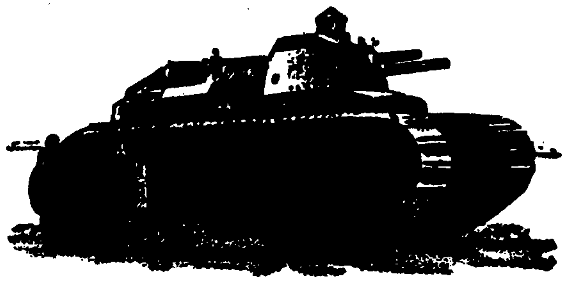

THE FIRST SOVIET RUSSIAN TANK, A RUSSIAN RENAULT, (1920)


U.S. CHRISTIE AMPHIBIOUS TANK OF 6.5 TONS (1921)

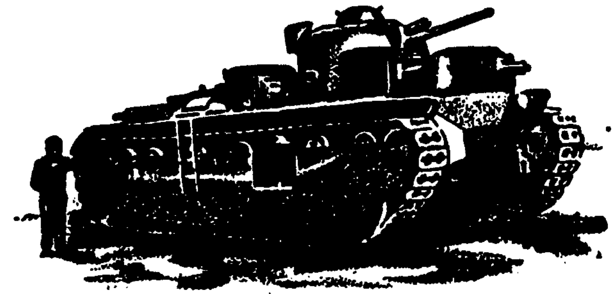

FRENCH ST. CHAMOND WHEEL-TRACK TANK, ON TRACK DRIVE (1921)


FRENCH ST. CHAMOND WHEEL-TRACK TANK ON WHEEL DRIVE (1921)

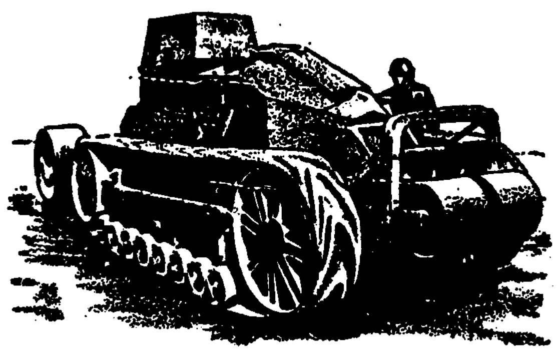

BRITISH VICKERS-ARMSTRONG MARK I (1922)



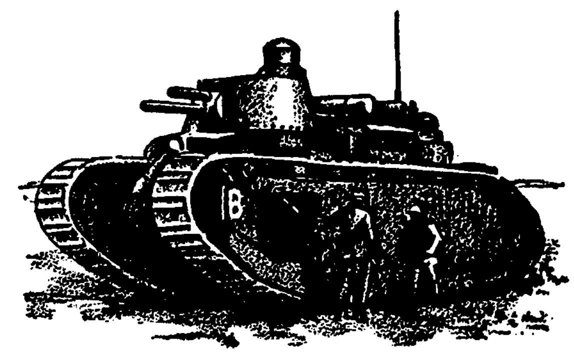
FRENCH HEAVY TANK 2C (1923)



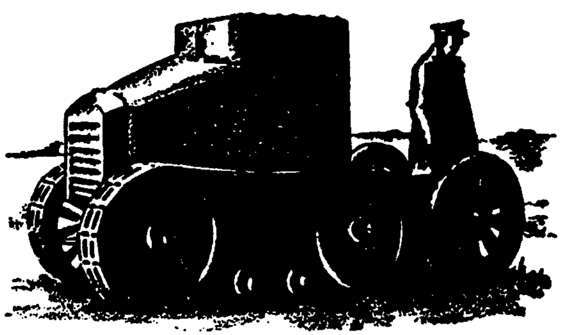
BRITISH HEAVY (34 TONS) TANK (1925)



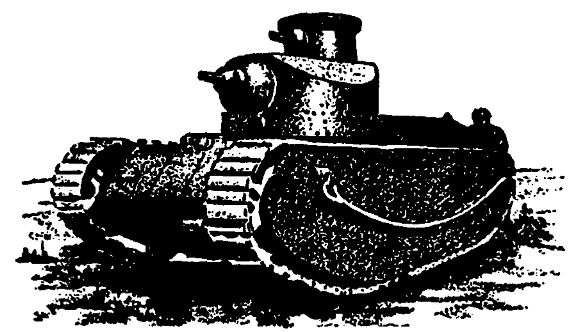
FRENCH LIGHT RENAULT TANK WITH RUBBER TRACKS (1924)



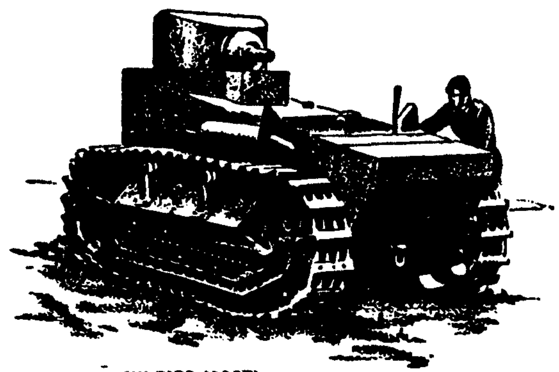
FRENCH HEAVY TANK 3C (74 TONS) (1926)



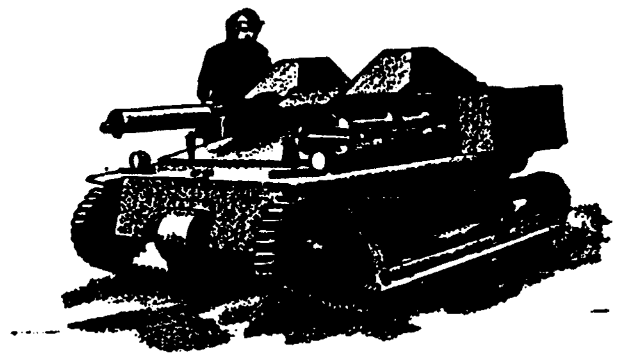
BRITISH MARTEL TANKETTE (1925)



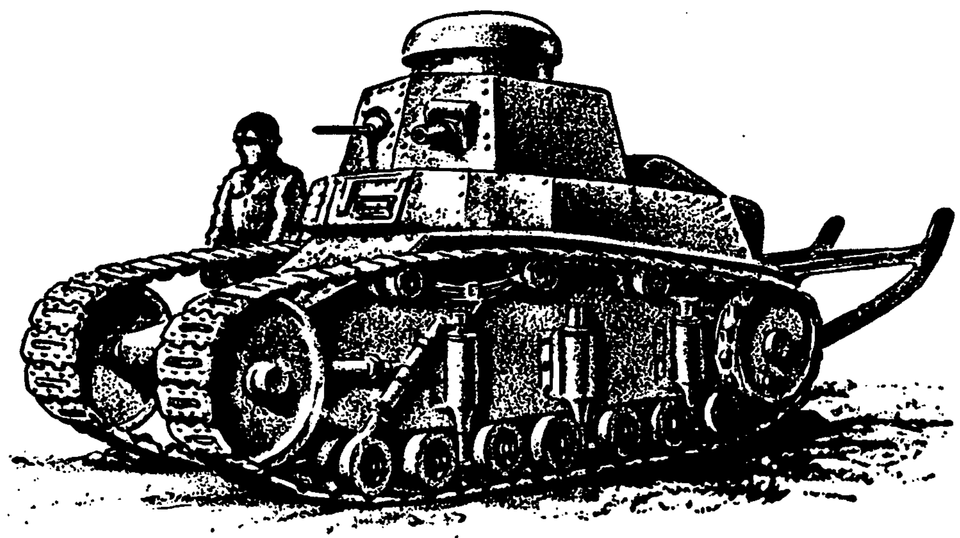
U.S. MEDIUM TANK (23 TONS) (1926)



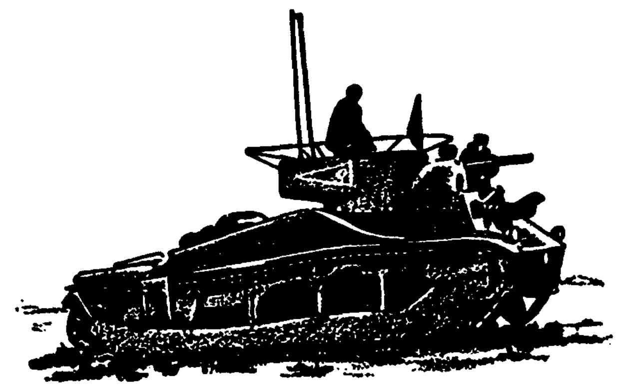
U.S. LIGHT TANK T1E2 (1927)



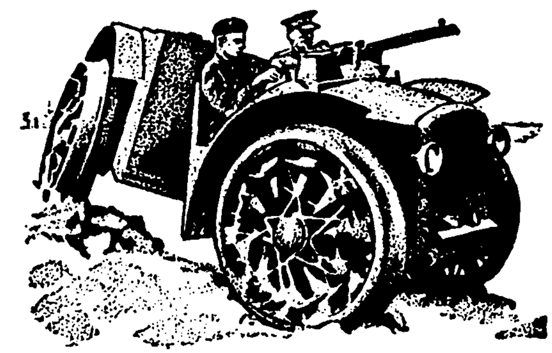
BRITISH CARDEN-LLOYD TANKETTE (1929)



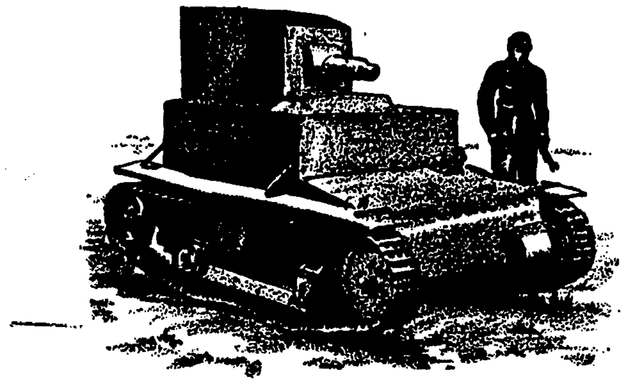
SOVIET MS-1 "SMALL ESCORT" TANK (1927)



BRITISH MEDIUM VICKERS (16 TON) TANK (1929)

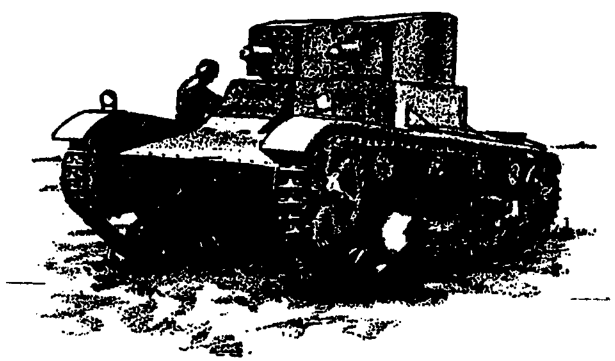


ITALIAN CROSS COUNTRY PRIME MOVER WITH SWIVEL CHASSIS (PAVEZIA) (1930)

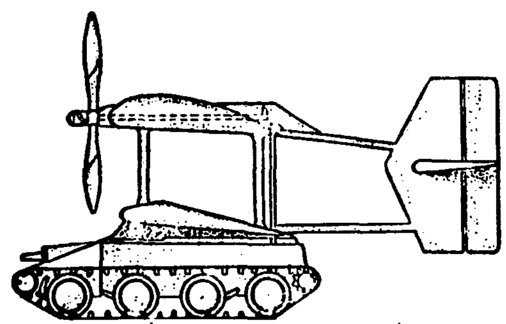


BRITISH VICKERS-CARDEN-LLOYD RECONNAISSANCE TANK (1930)

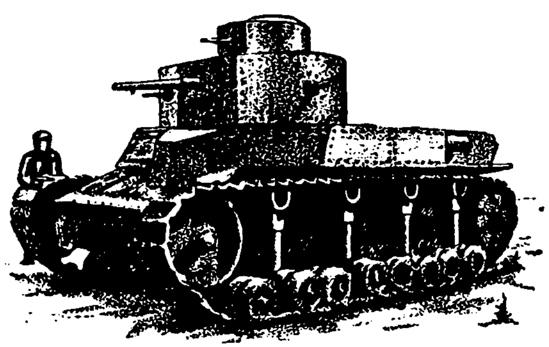
BRITISH VICKERS AMPHIBIOUS TANK OF 3 TONS (1931)



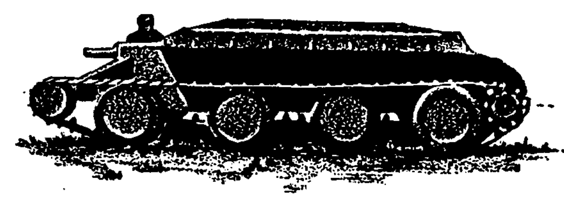
BRITISH LIGHT VICKERS (6 TON) TANK (1930)



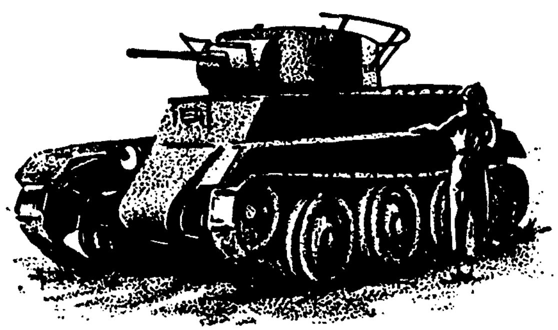
U.S. FLYING TANK, A 1932 CONCEPT OF CHRISTIE.



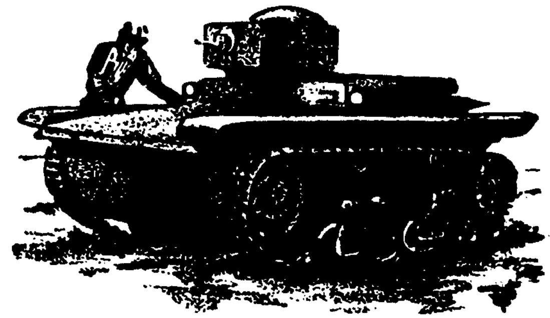
SOVIET T-24 TANK (1930)



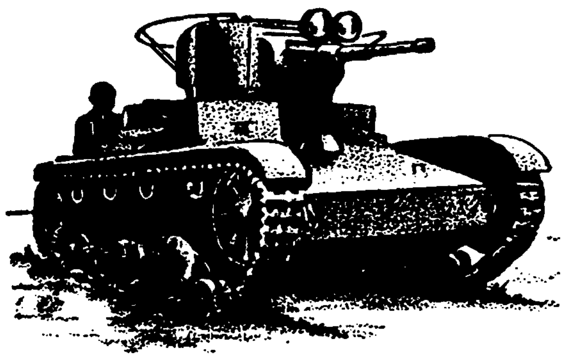
U.S. SUPERFAST CHRISTIE TANK (1932)



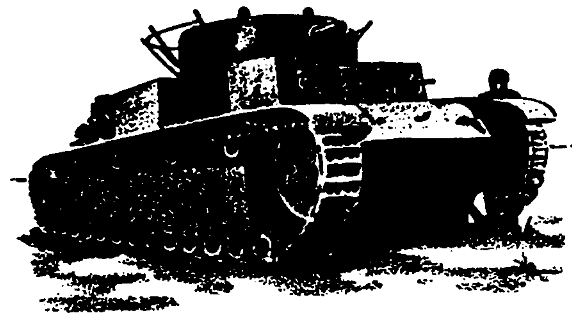
SOVIET HIGH-SPEED, WHEELED-TRACKED TANK BT (1932)



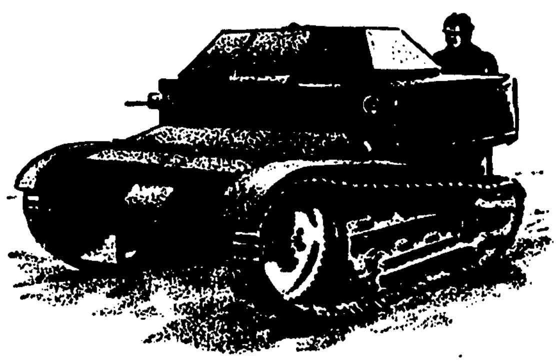
SOVIET AMPHIBIOUS T-37 TANK; TWO-MAN CREW; WEIGHT: 3.5 TONS (1932)



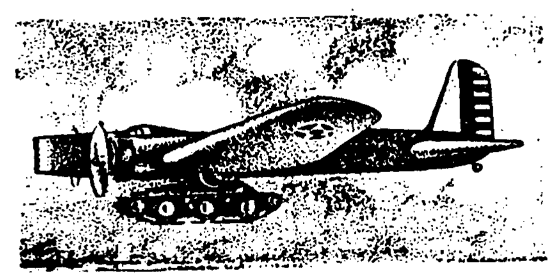
SOVIET LIGHT, THREE MAN TANK, THE T-26 (1932)



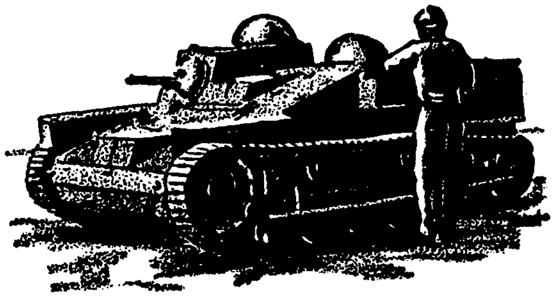
SOVIET 3-TURRETED MEDIUM TANK, T-28; 6-MAN CREW (1933)



SOVIET TWO-MAN TANKETTE T-27 (1932)

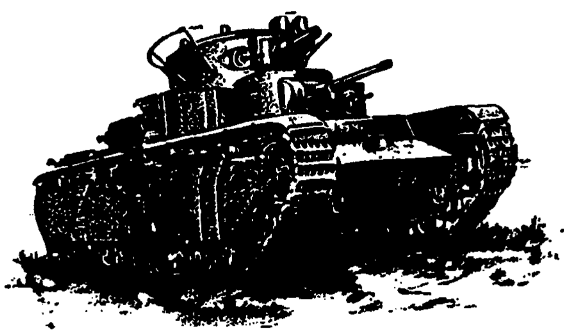


U.S. CHRISTIE PROPOSAL OF A LIGHT TANK SUSPENDED FROM AIRCRAFT (1933-35)

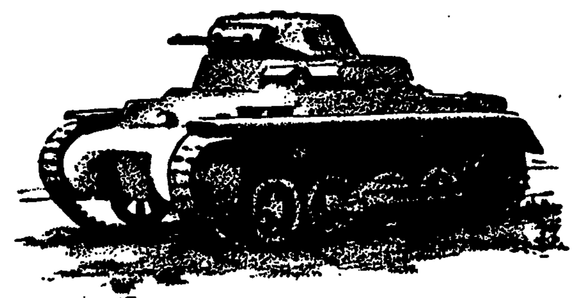


FRENCH RENAULT TANKETTE (1933)

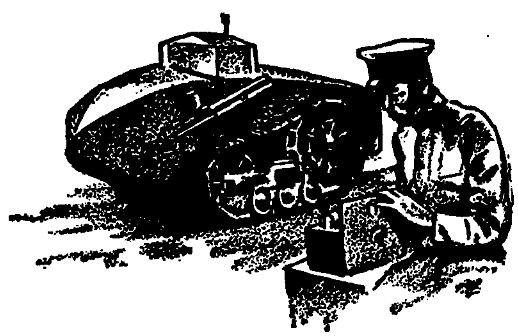
FRENCH LIGHT R-35 TANK (1935)



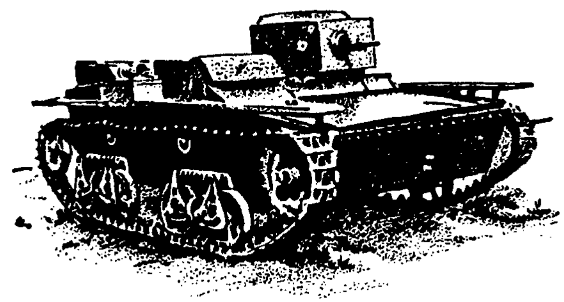
SOVIET 5-TURRETED HEAVY T-35 TANK; 9-MAN CREW (1933)



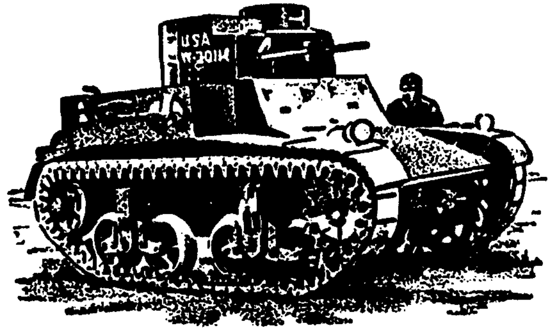
GERMAN LIGHT TANK T-1. THE FIRST TANK CONSTRUCTED AFTER GERMANY'S VIOLATION OF THE VERSAILLES TREATY. RELEASED 1935. (THE SPANISH CIVIL WAR POINTED OUT WEAKNESSES IN THE T-1 SO THE T-IIB FOLLOWED ABOUT 1937.



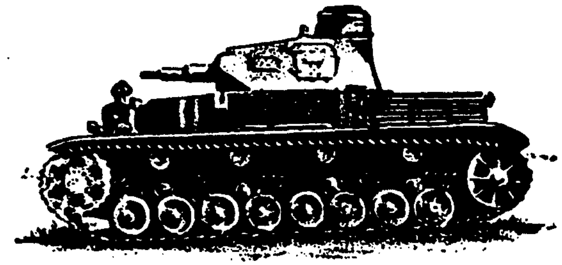
JAPANESE REMOTE (RADIO) CONTROLLED TANK (1934)



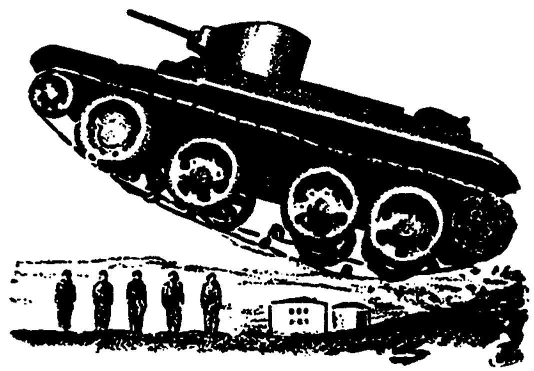
SOVIET AMPHIBIOUS T-38 TANK, 2 MAN CREW; WEIGHT 3.3 TONS (1935)



U.S. LIGHT TANK T-5 (1936)

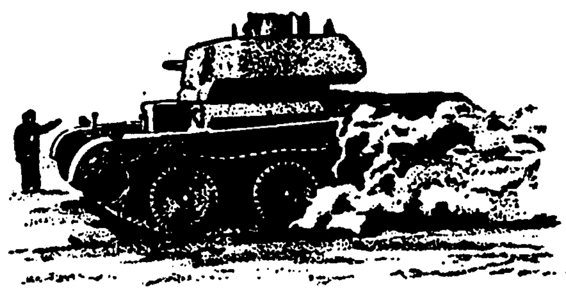


GERMAN MEDIUM T-IV TANK (1939)

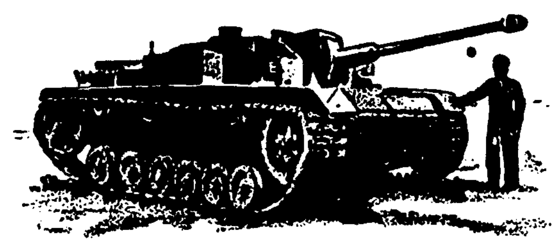


SOVIET BT TANK (1936)

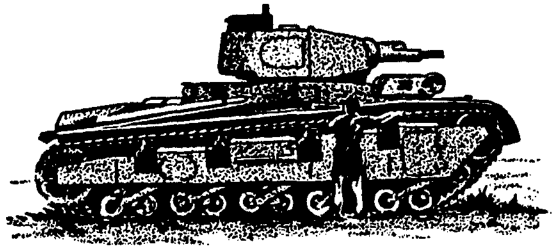
GERMAN MEDIUM TANK T-III, THE BASIC MASS-PRODUCED TANK OF THE FIRST PART OF WWII (1939)



BRITISH CRUISER TANK A-13 (1938)

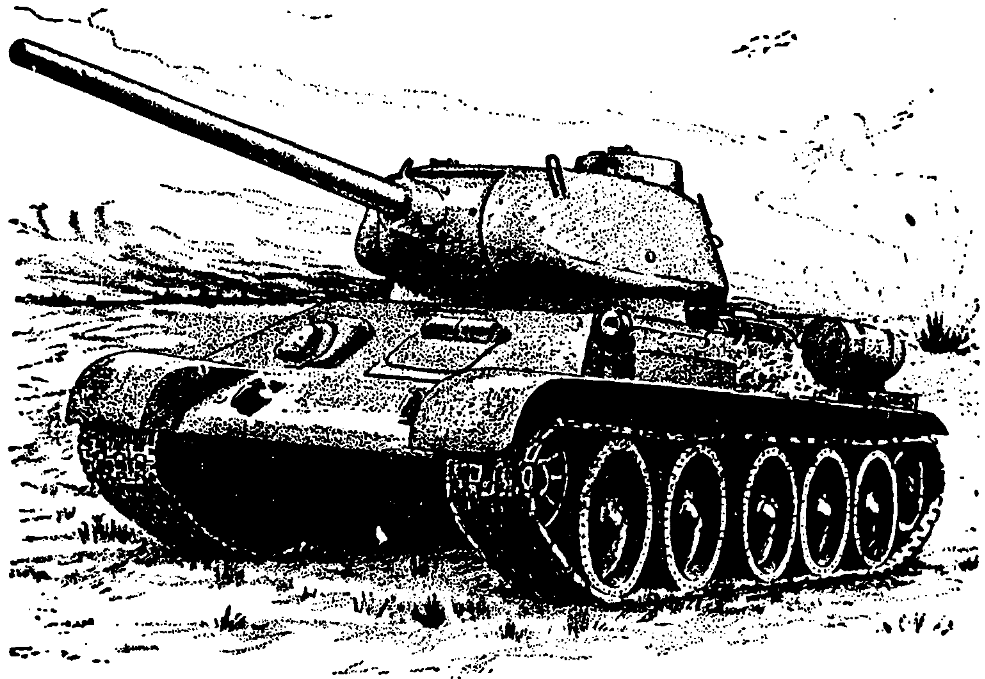


GERMAN SELF-PROPELLED ASSAULT (75MM) GUN MOUNTED ON A T-III TANK (1939)

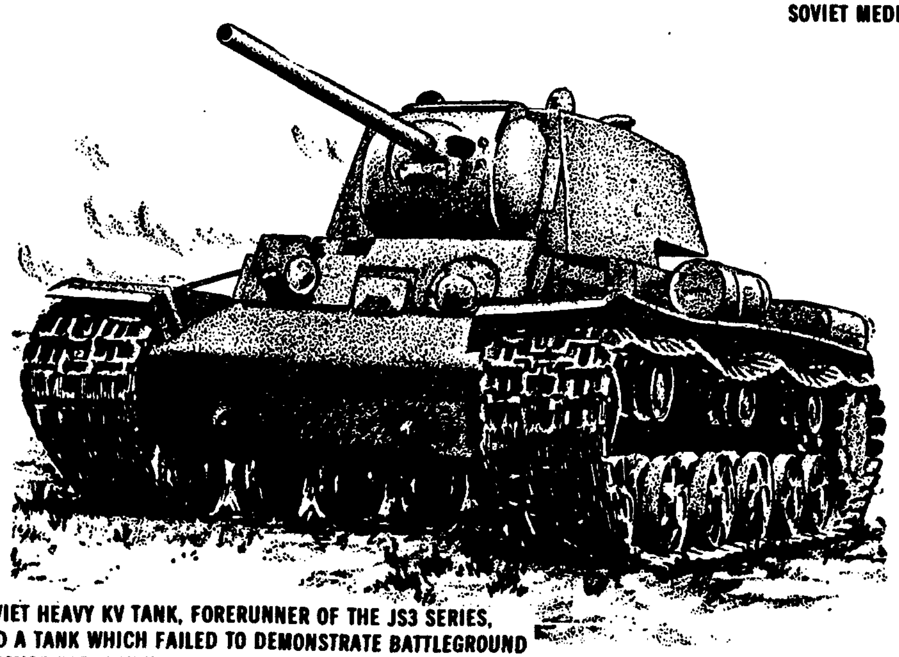


GERMAN HEAVY RHEINMETALL TANK (1939)

BRITISH MEDIUM TANK, THE MATILDA M-II (1939)

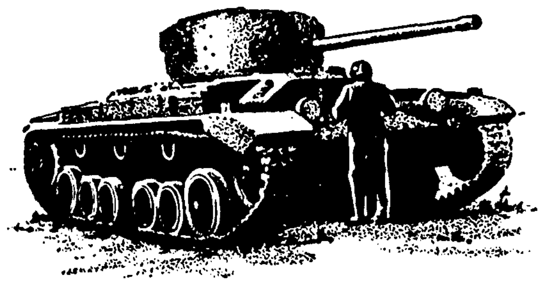


SOVIET MEDIUM T-34 TANK (1940)

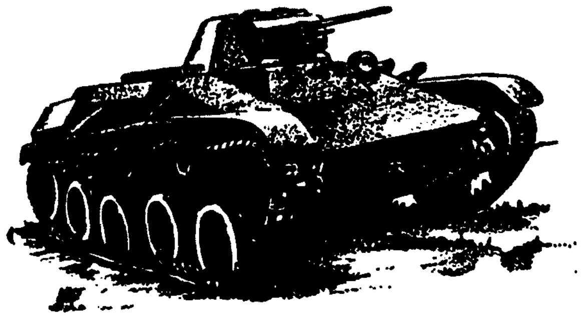


SOVIET HEAVY KV TANK, FORERUNNER OF THE JS3 SERIES, AND A TANK WHICH FAILED TO DEMONSTRATE BATTLEGROUND PROMISE EARLY IN WWII. (1940)

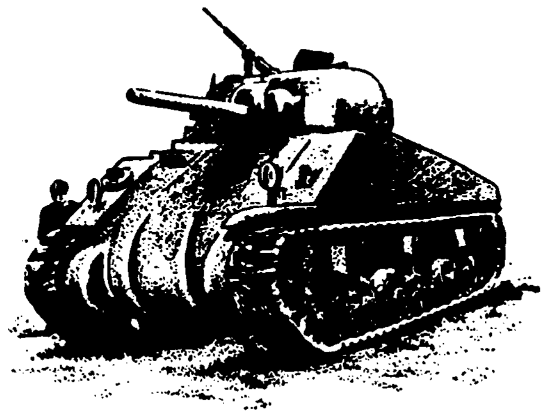
SOVIET AMPHIBIOUS T-40 TANK; 2-MAN CREW; WEIGHT: 5.8 TONS (1940)



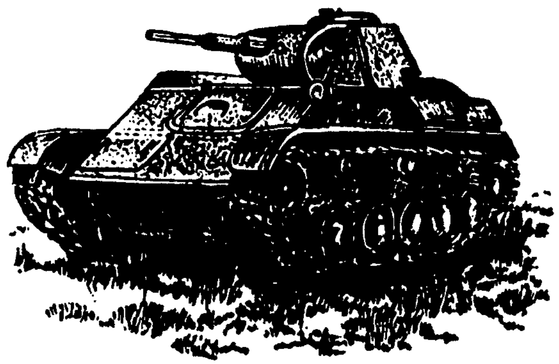
BRITISH LIGHT TANK, THE VALENTINE M-III (1940)



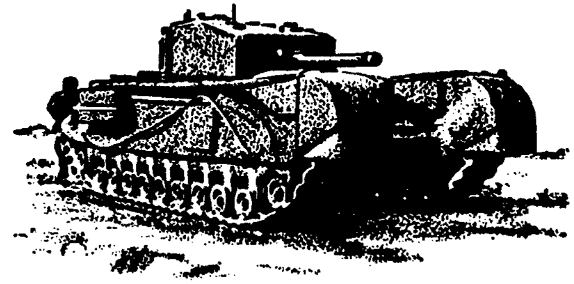
SOVIET LIGHT T-60 TANK (1941)



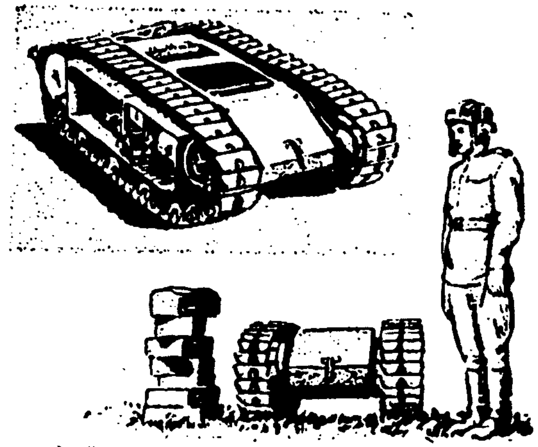
U.S. MEDIUM (M4-A2) SHERMAN TANK (1941)



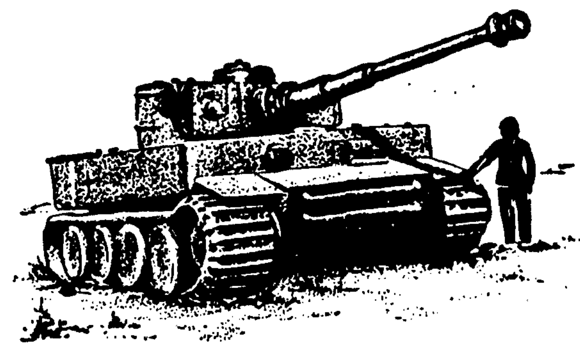
SOVIET LIGHT T-70 TANK; TWO-MAN CREW; 10 TONS (1942)



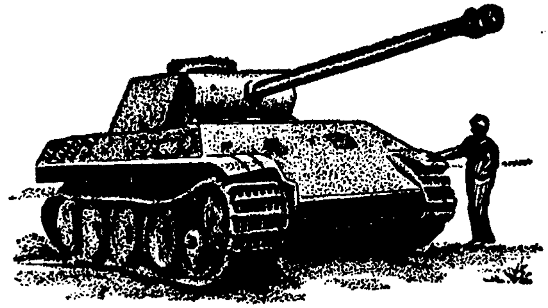
BRITISH HEAVY TANK, THE CHURCHILL M-IV (1942)



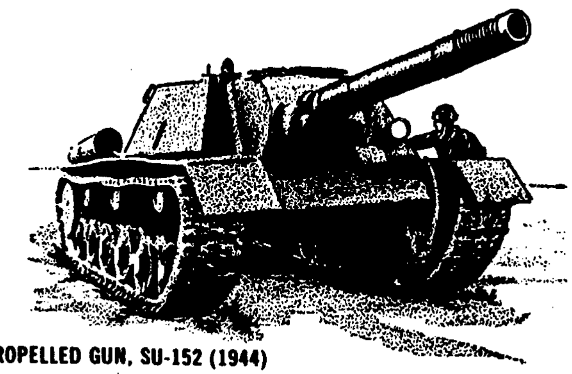
GERMAN SELF-PROPELLED TRACK LAYING "TORPEDO" (1943)



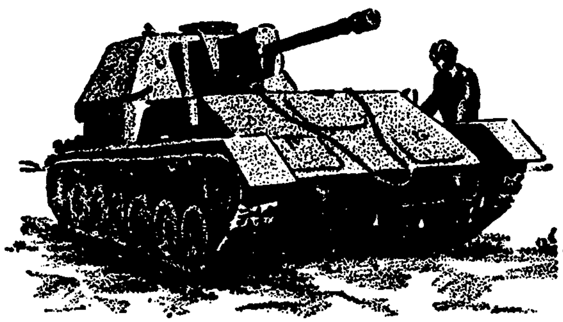
GERMAN TIGER TANK (1943)



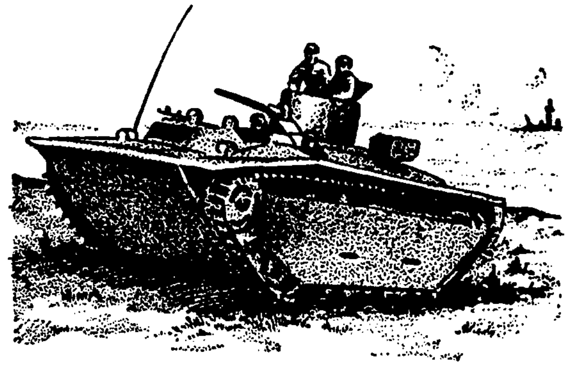
GERMAN PANTHER TANK (1943)



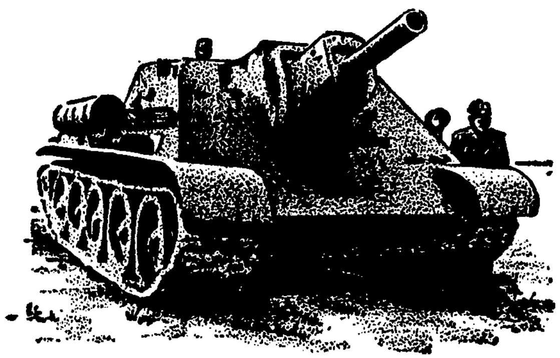
SOVIET SELF-PROPELLED GUN, SU-152 (1944)



SOVIET SELF-PROPELLED GUN, SU-76 (1944)



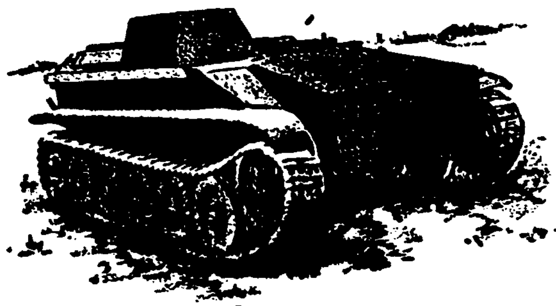
U.S. AMPHIBIOUS TANK (1944)



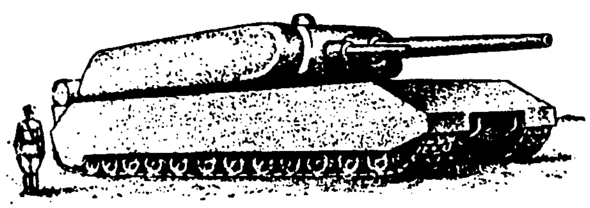
SOVIET SELF-PROPELLED GUN, SU-122 (1944)

BRITISH MEDIUM TANK, THE CROMWELL (1944)

GERMAN ROYAL TIGER TANK (1944)

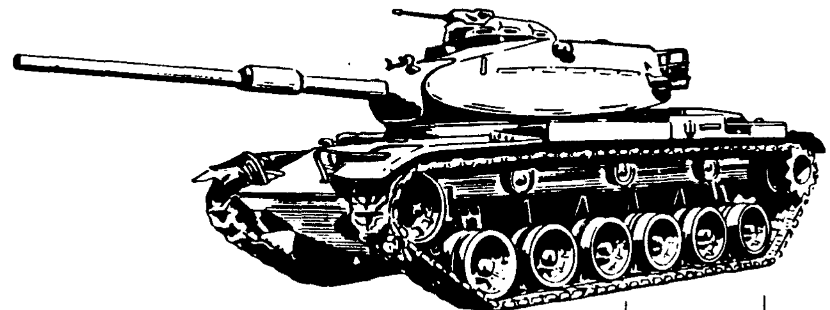


GERMAN V-4 REMOTE CONTROLLED TANK (1944)

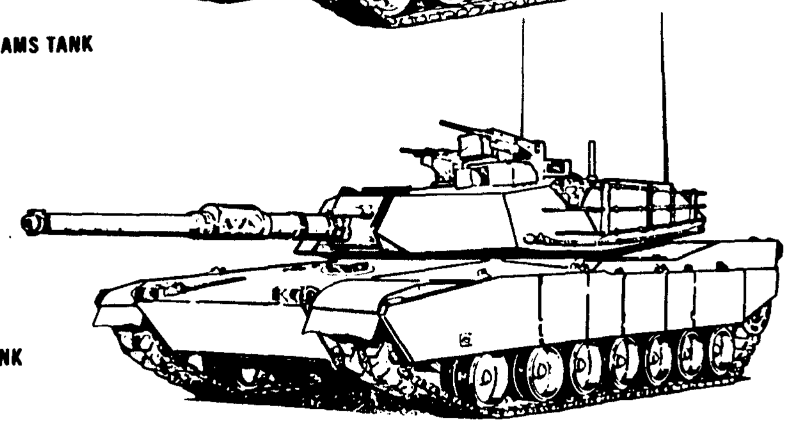


GERMAN SUPER-HEAVY TANK WITH ONE 128MM AND ONE 75MM GUN (1944)

SOVIET JOSEPH STALIN TANK (1945)



M1 ABRAMS TANK



M60 TANK

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